

Ansys Submission to 1st AIAA Transition Modeling Prediction Workshop

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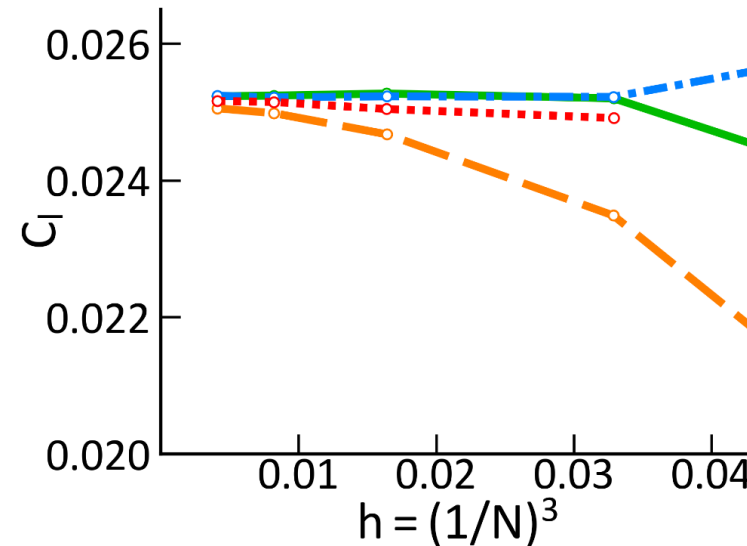
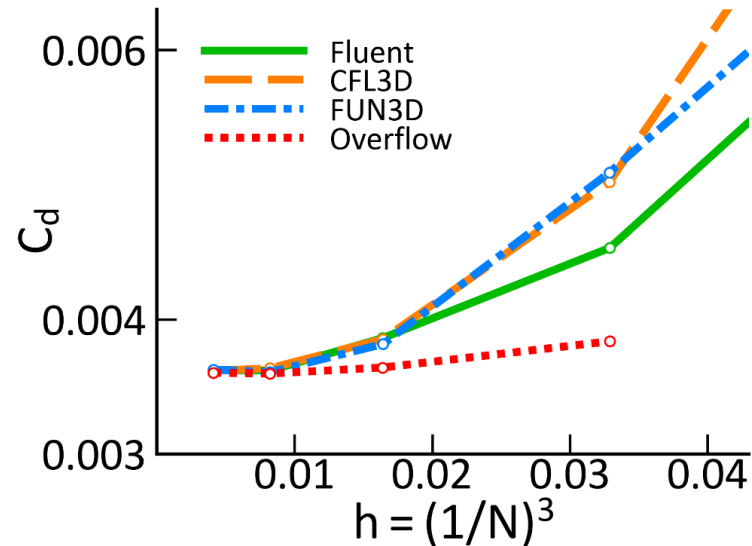
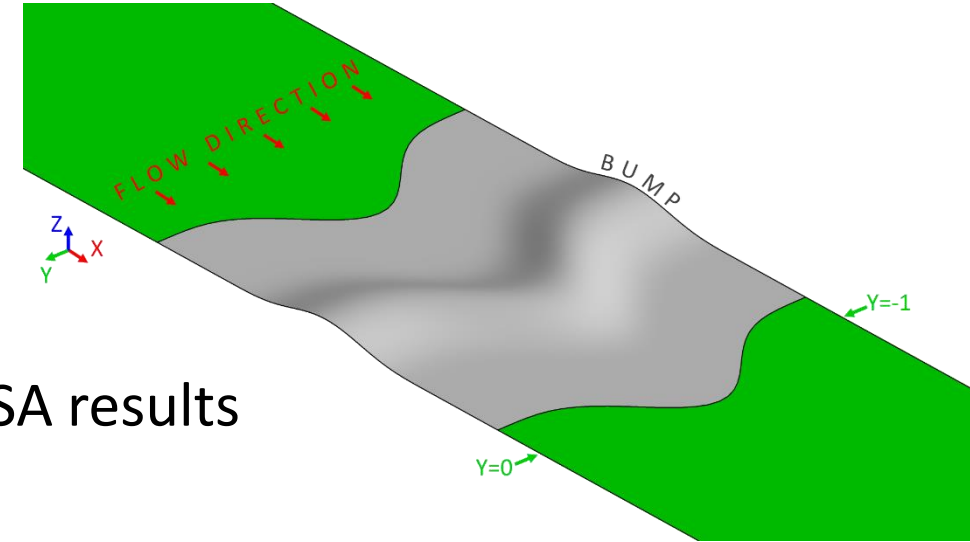
Outline

- Solver and transition model
- Summary of results and key observations
 - Case 0 – Turbulence model verification
 - Case 1 – Flat Plate
 - Case 2 – 2D Airfoil
 - Case 4 – NLF CRM
 - Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$
 - Case 4B: α -Sweep Study with Transition
 - Case 4C: α -Sweep Study, Fully Turbulent
- Summary and Outlook

- General description
 - Cell-centered finite volume method
 - Pressure and density-based solution methods
 - Selection of p-v coupling, spatial discretization and gradient calculation options
 - Pseudo-transient and CFL-based steady-state solution advancement
 - Various initialization options
 - Full suite of turbulence models (RANS, RSM, LES, hybrid RANS-LES, ...)
 - Broad range of additional physics
 - CHT, non-equilibrium thermodynamics, chemical reactions, radiation, multi-phase, ...
- Turbulence transition model applied in all workshop cases:
 - Two-equation SST turbulence model with two-equation γ - Re_θ model for laminar-turbulent transition
 - a.k.a. Langtry-Menter 4-equation Transitional SST Model (“SST-2003-LM2009”)
 - Default Fluent SST model with Kato-Launder production limiter $P_k = \mu_t \Omega S - \frac{2}{3} \rho k \delta_{ij} \frac{\partial u_i}{\partial x}$ (“SST-KL”)

Case 0 – Turbulence Model Verification

- Channel with span-wise varying bump on surface
- Fully turbulent flow with the default Fluent SST
- Grid-converged results consistent with reference NASA results

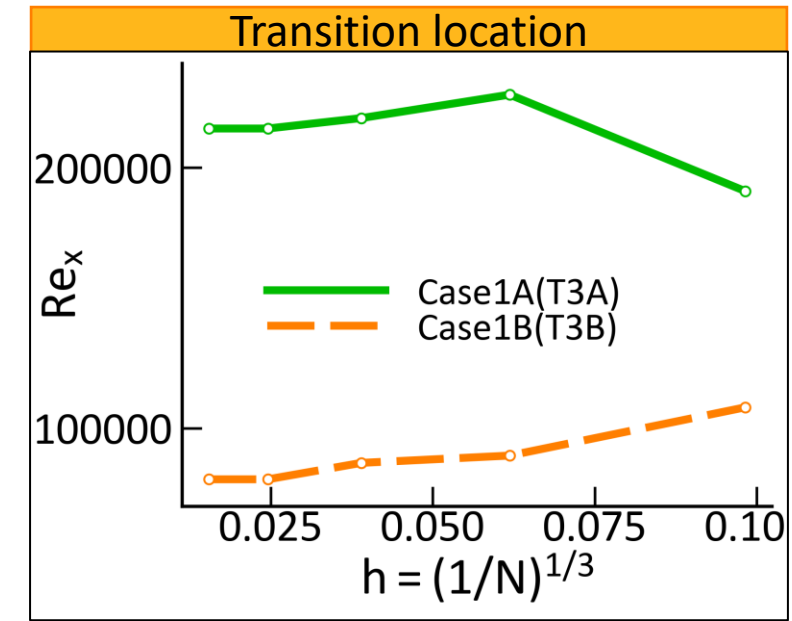
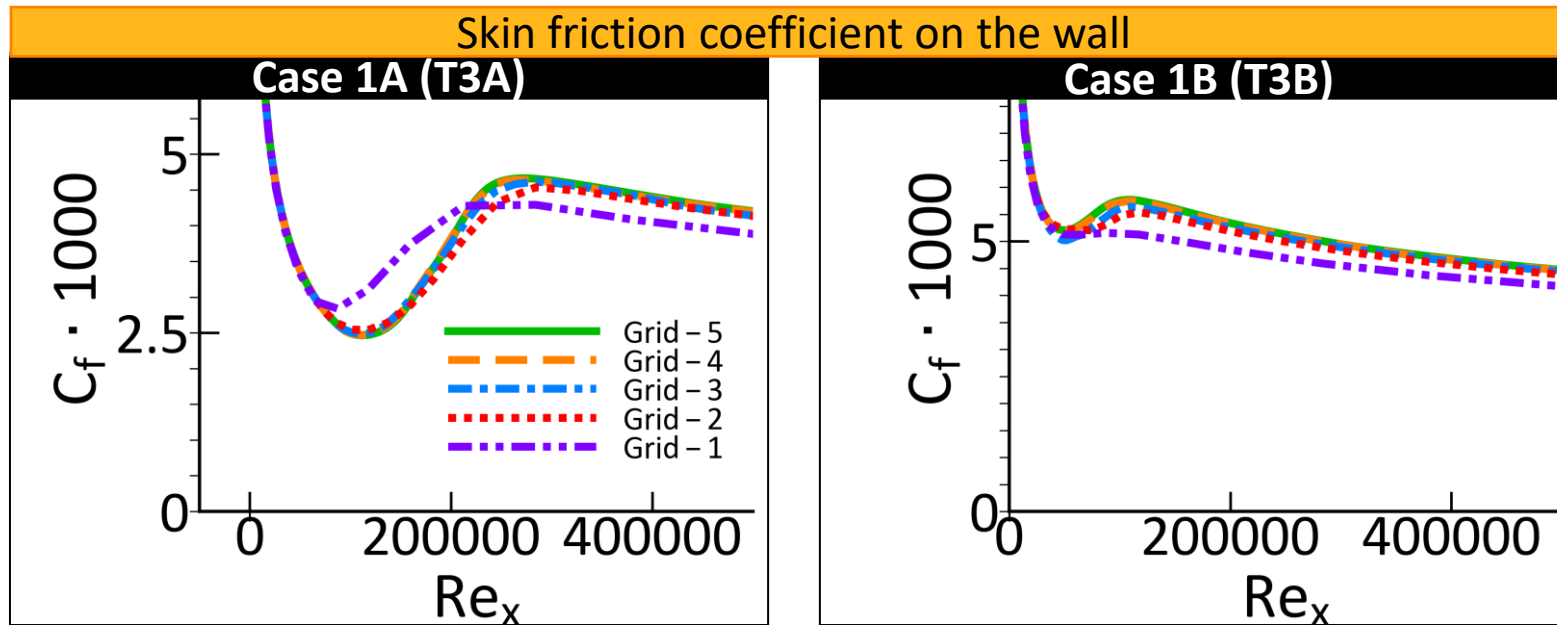


Case 1 – Flat Plate

- Grid resolution study on smooth, flat plate with variation of inlet turbulence conditions
 - Case 1A (T3A): $Tu = 5.855\%$, $v_t/v = 11.9$
 - Case 1B (T3B): $Tu = 7.216\%$, $v_t/v = 99$
- Grid-converged results

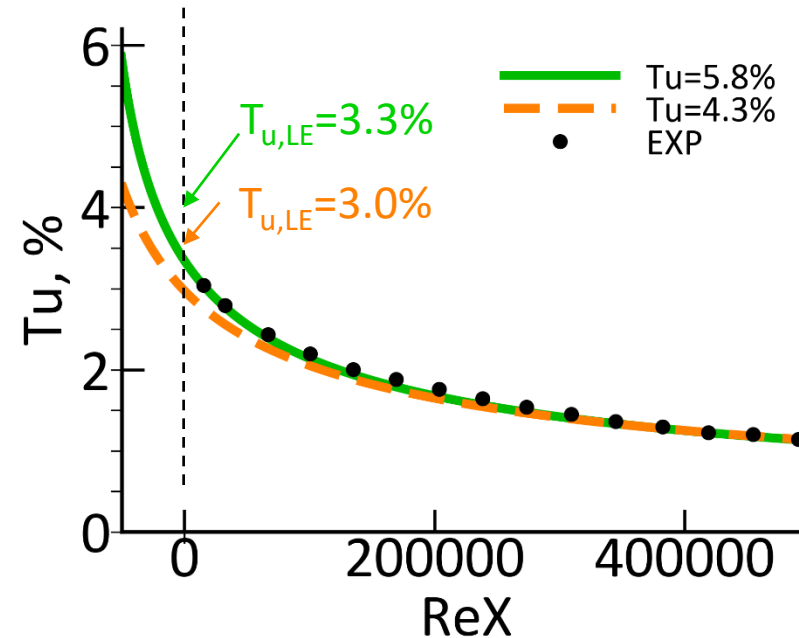
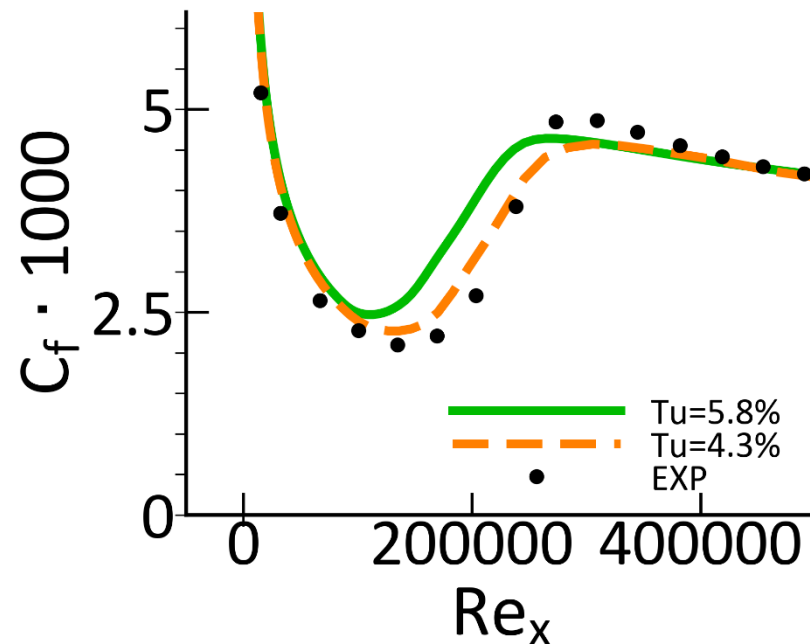
The workshop-provided computational grids are used

Grid	Grid-1	Grid-2	Grid-3	Grid-4	Grid-5
X x Y (Nodes)	45 x 25	89 x 49	177 x 97	353 x 193	705 x 385



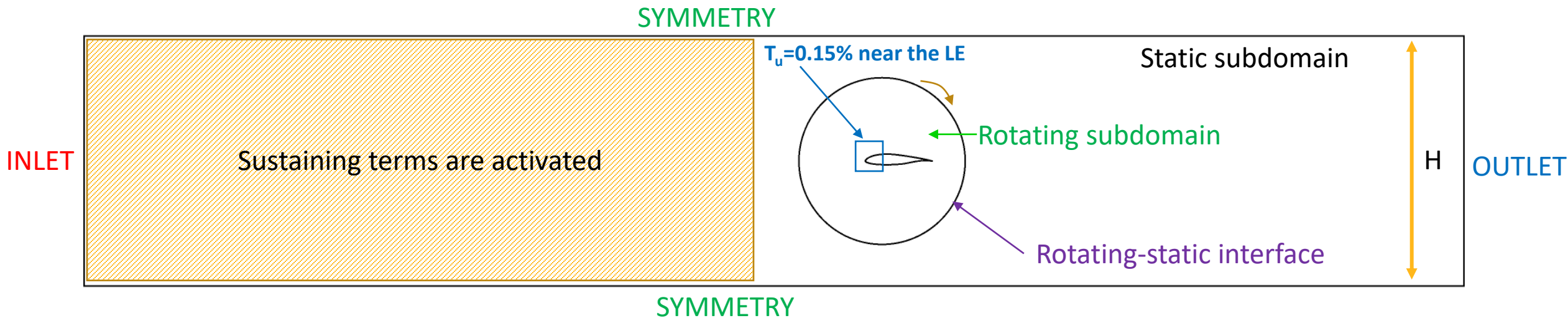
Case 1 – Flat Plate

- Observation: Effect of (sensitivity to) inlet turbulence Case1A (T3A)
 - ERCOFTAC database
 - Noticeable shift in transition onset location
 - Smaller effect on freestream turbulence along length of plate



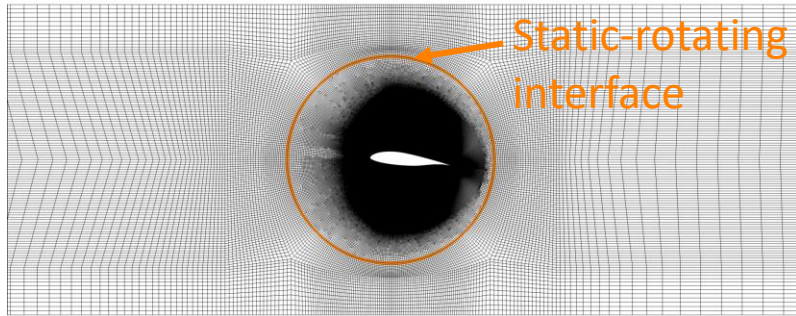
Case 2: Flow Around an NLF(1)-0416 Airfoil (2D)

- Compressible Flow
 - $Re = 4 \cdot 10^6$, $Ma = 0.1$, $T = 300K$, $Pr=0.71$
- Wind tunnel computational domain with rotating airfoil and experimental height ($H/C = 3.75$)
 - Two non-overlapping subdomains
 - Rotating part with airfoil (rotation point: $X/C=0.25$)
 - Static part in the wind tunnel
- Sustaining terms are used to ensure $T_u=0.15\%$ on the airfoil leading edge

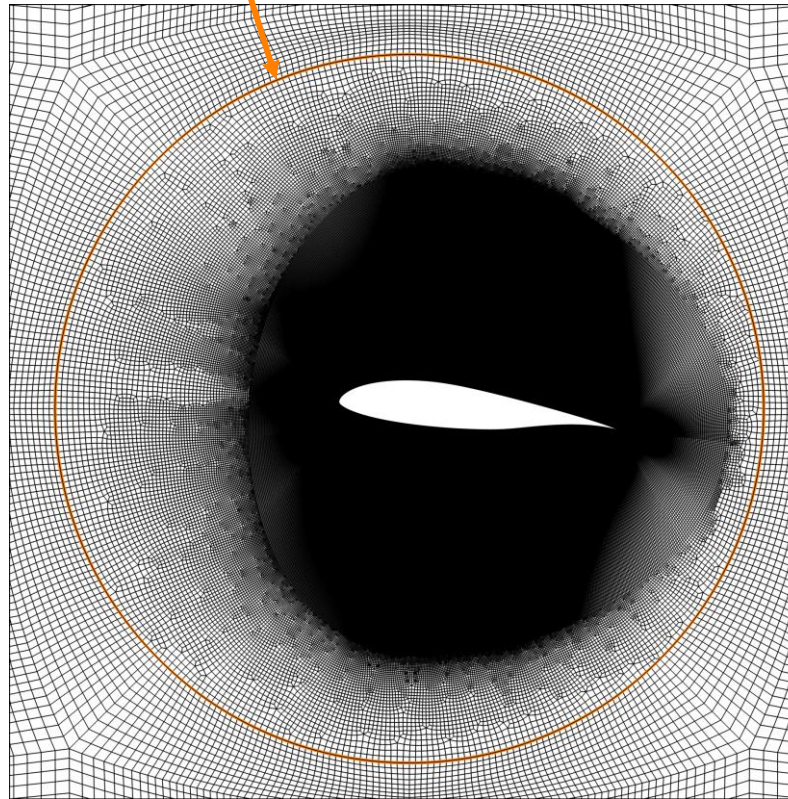


Case 2: Computational Grids and Grid Convergence Study

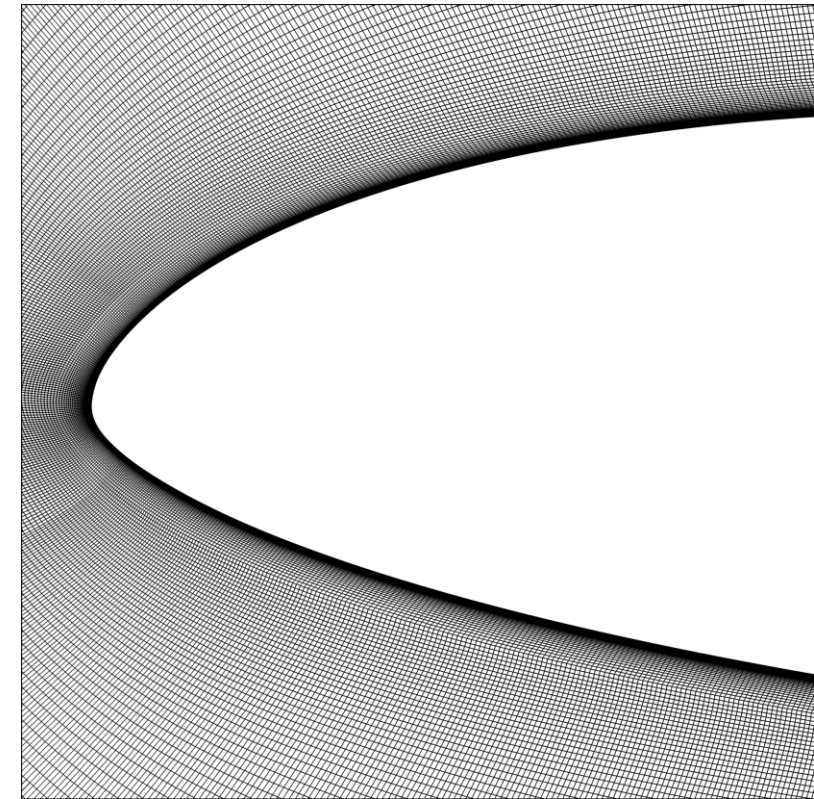
- Ansys-created grids
 - Structured grid around the airfoil and in the tunnel
 - Unstructured hexahedral grid near the static-rotating interface



- 1 degree grid step on the interface
- 1:1 connection for the integer-valued angle of attack



- For all the grids
 - $\Delta Y^+_{1,\max} < 1$
 - ER = 1.08 (Expansion ratio) in wall-normal direction



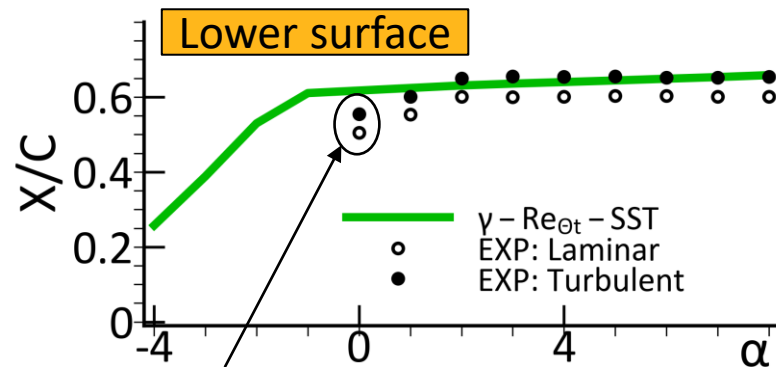
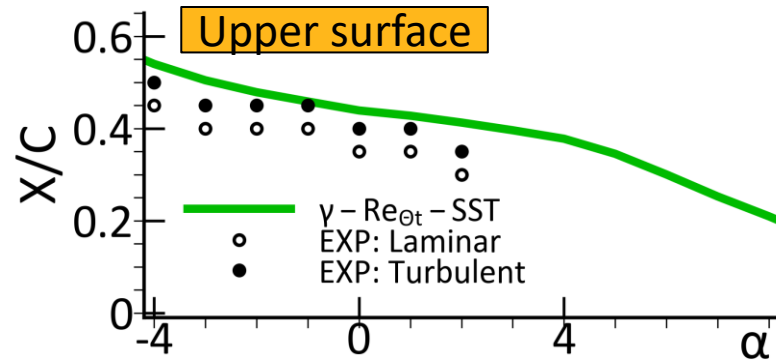
Grid	Grid-1	Grid-2	Grid-3
N cells	152 570	357 559	1 162 970

- Results on all the grids agree with each other
- Main results are presented for Grid-2

Case 2: Comparison Results with the Experimental Data

Transition location

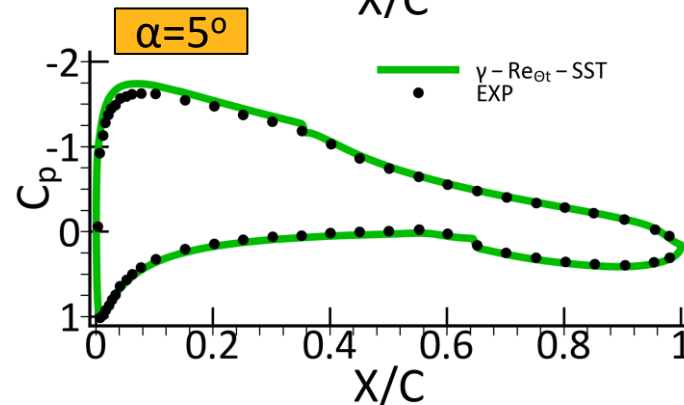
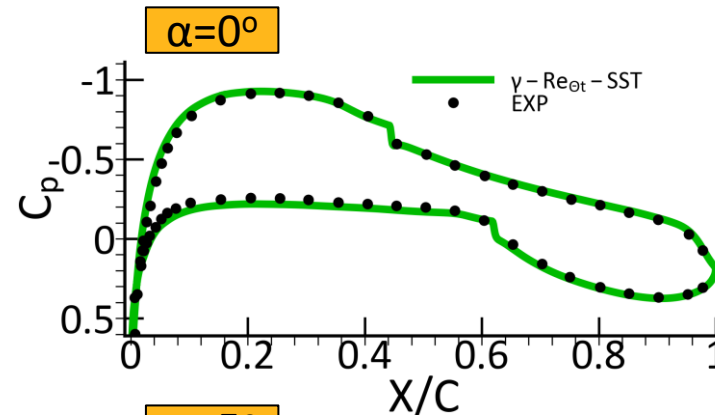
- γ - Re_{θ} -SST model delays transition prediction on the upper surface
 - The model tends to predict bubble transition instead of natural transition



In the experiment natural transition occurs between open (○) and solid (●) symbols

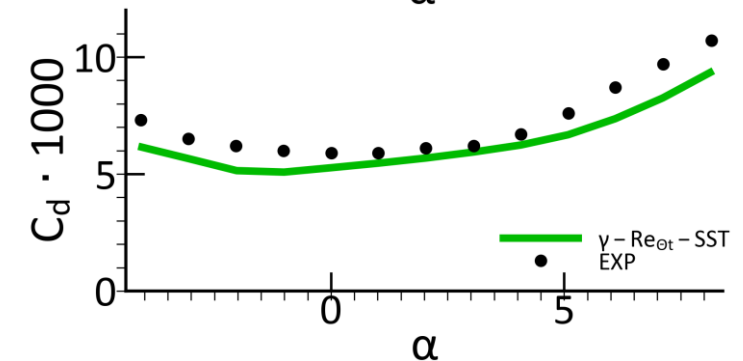
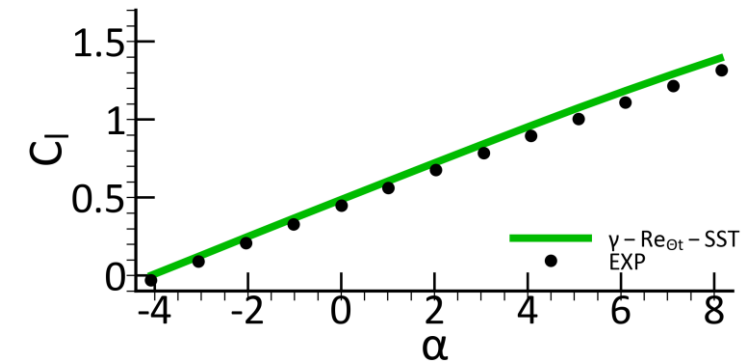
Pressure description

- Pressure distribution prediction in a good agreement with the experimental data



Aerodynamic forces

- The model slightly underpredicts C_d
 - The most possible reason is the delay of the transition prediction on the upper surface

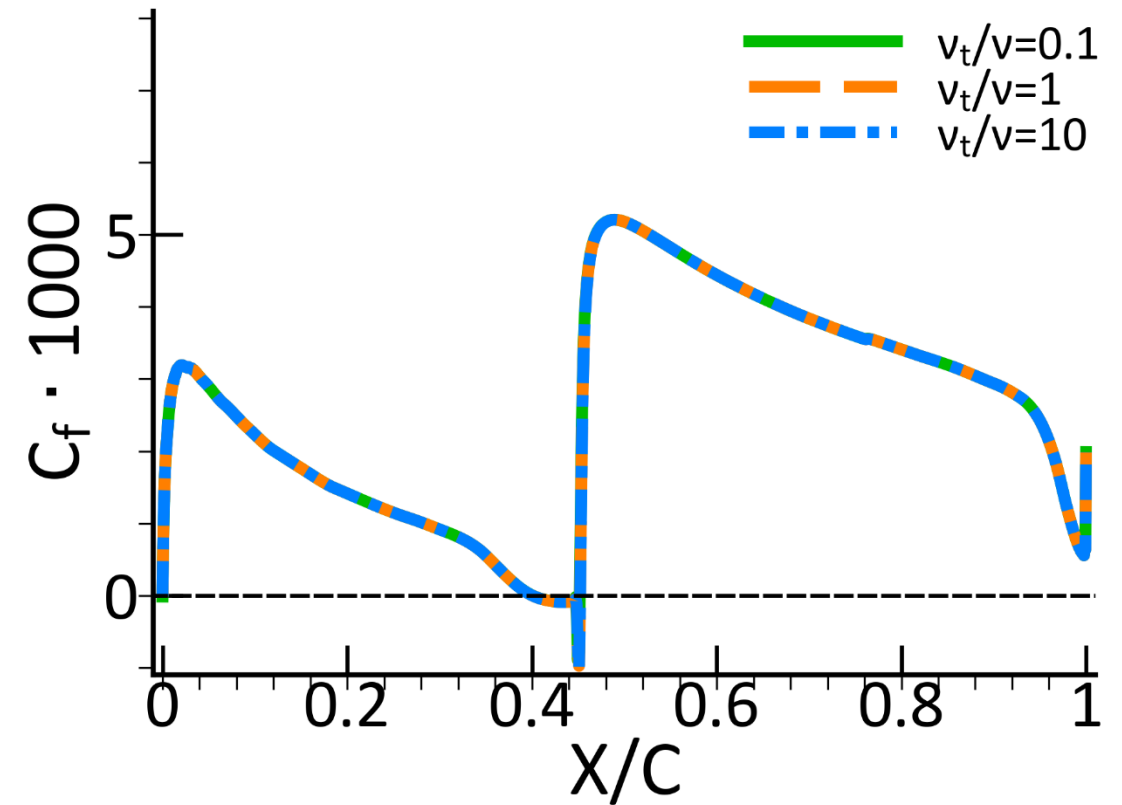
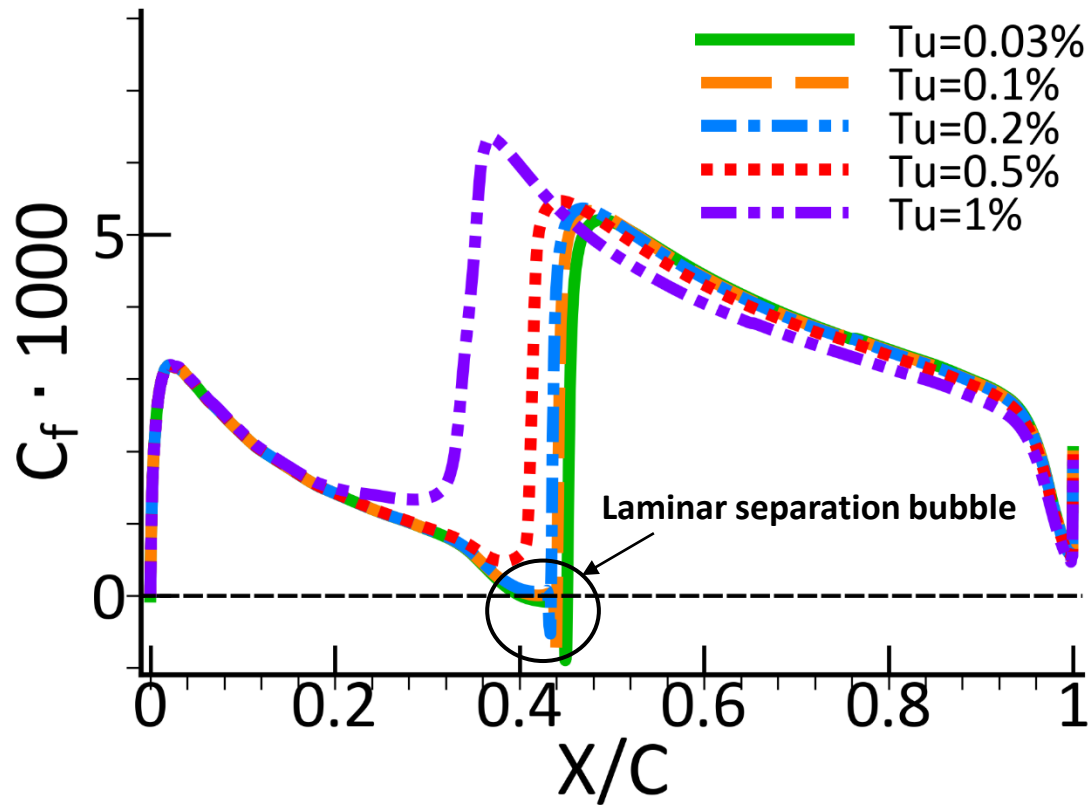


Reference experimental paper: NASA TP 1861
<https://ntrs.nasa.gov/citations/19810015487>

Case 2: Sensitivity to Inlet Turbulence Characteristics

- The solution becomes insensitive to freestream eddy viscosity ratio and freestream with $T_u < 0.2\%$

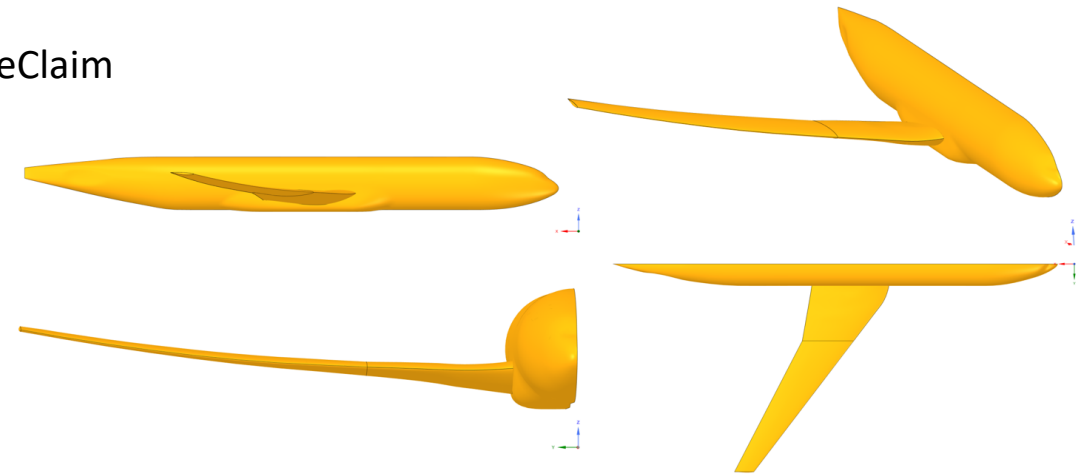
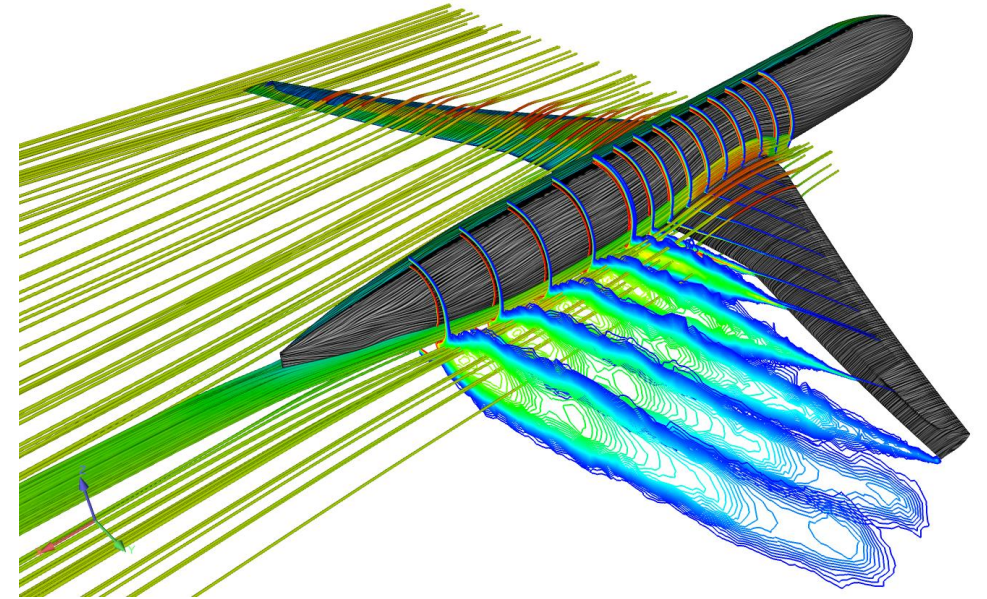
Skin friction coefficient on the upper surface at $\alpha=0^\circ$



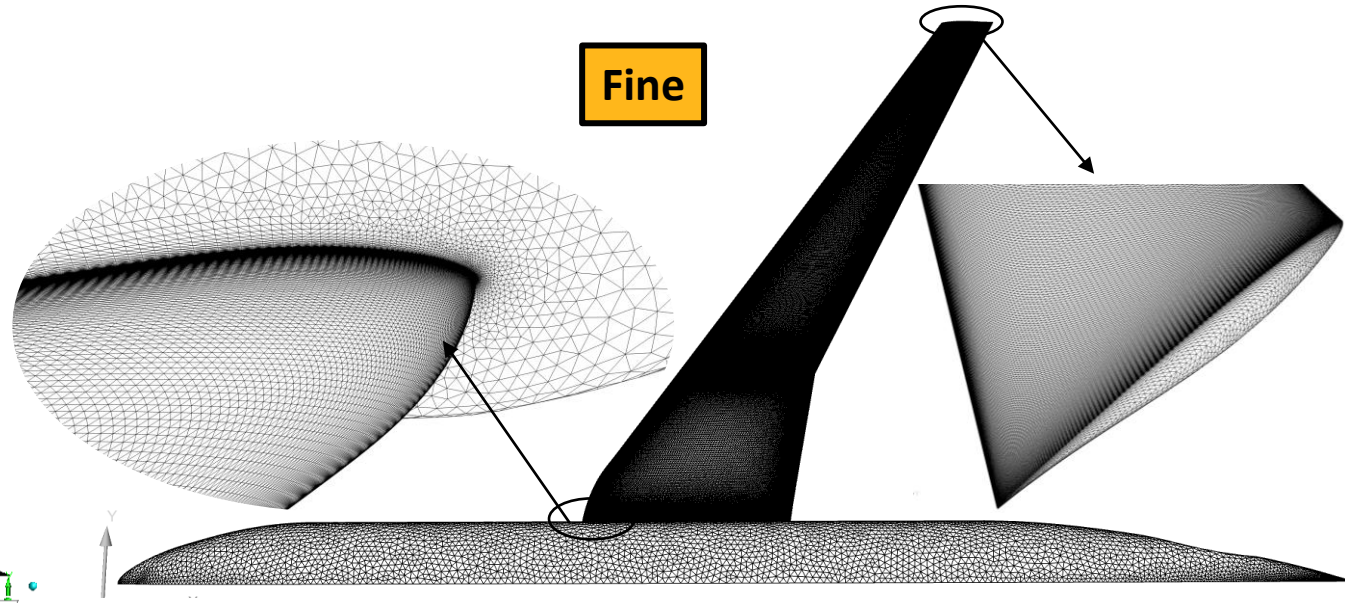
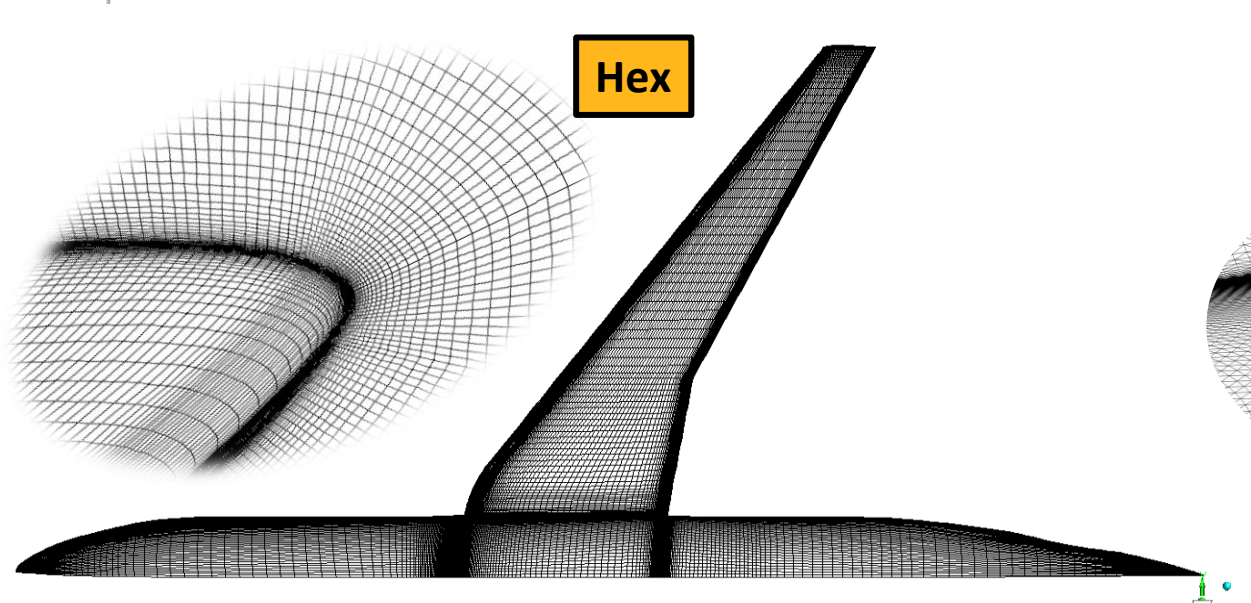
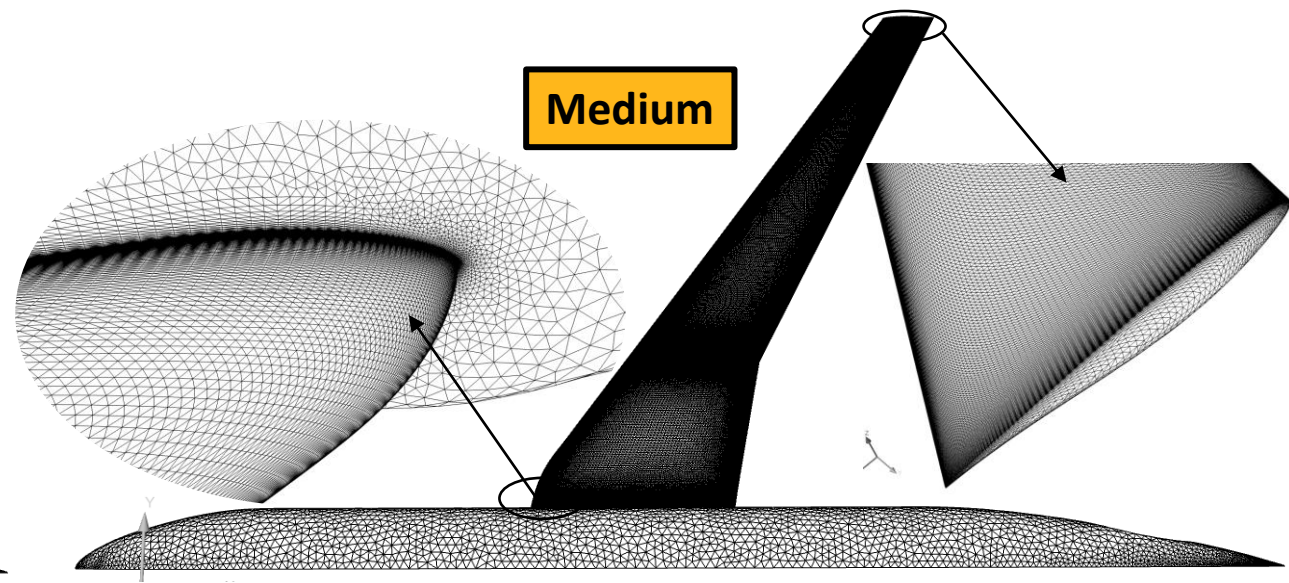
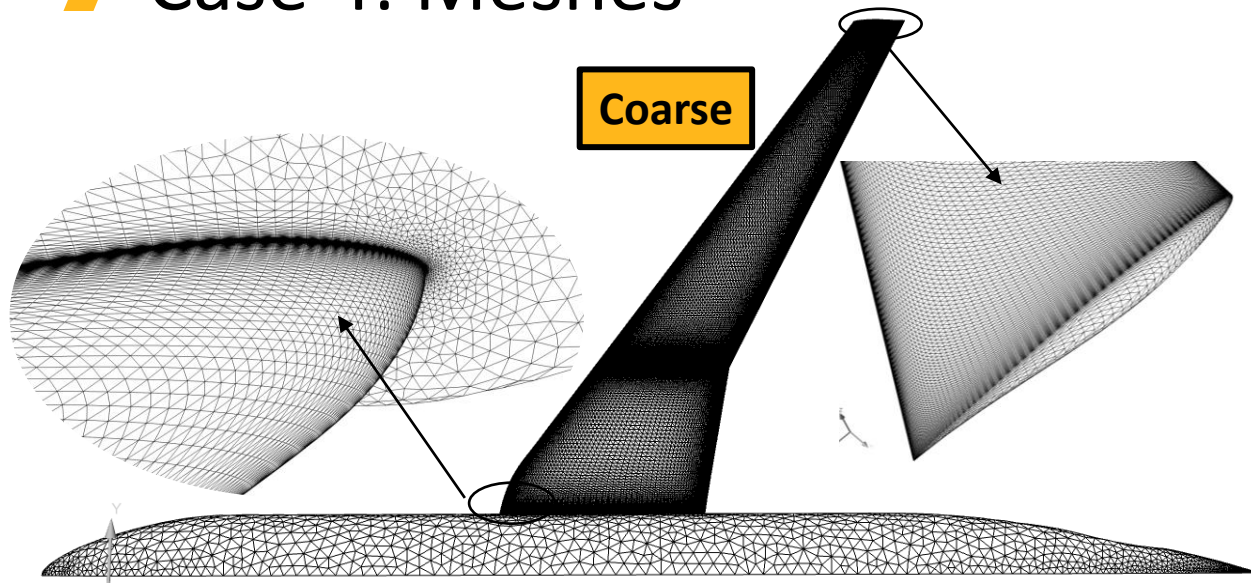
Case 4: CRM-NLF Geometry

- Case 4A: Grid-resolution study with transition
- Case 4B: α -sweep using medium-resolution grid
- Case 4C: Grid-resolution study – fully turbulent
- Meshes
 - Workshop-provided (prism-tet)
 - Ansys-created (structured hex)
 - Based on IGES model, scaled to tunnel model in Ansys SpaceClaim

	Nr. of cells
Coarse prism-tet (Tmesh8)	7,008,758
Medium prism-tet (Tmesh12)	21,164,168
Fine prism-tet (Tmesh16)	47,367,515
Hex	14,201,856



Case 4: Meshes



Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$

- Observation on integral quantities on workshop-provided prism-tet meshes

- Not yet achieved grid convergence

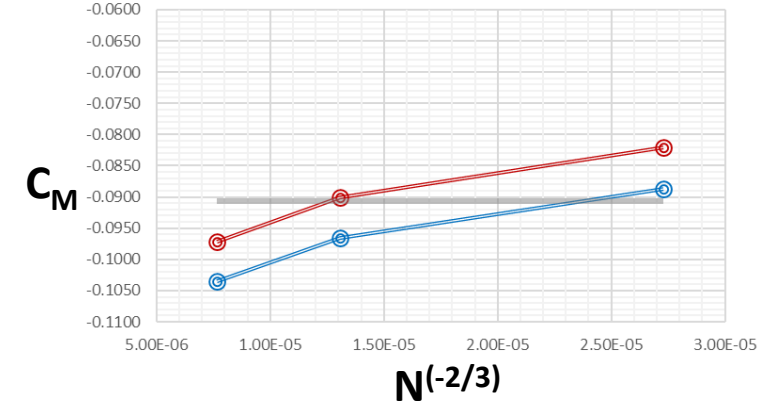
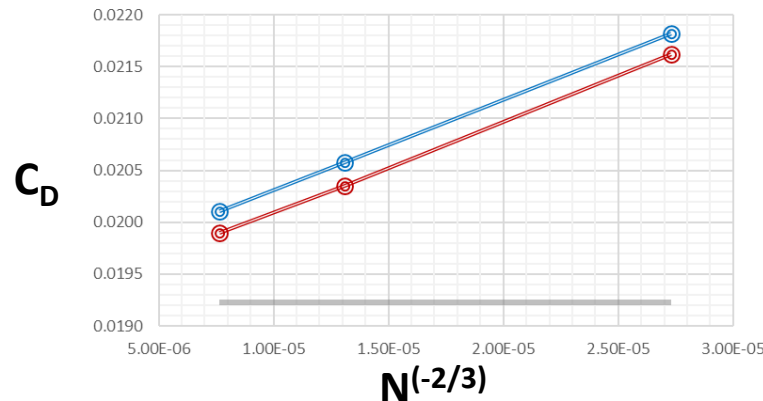
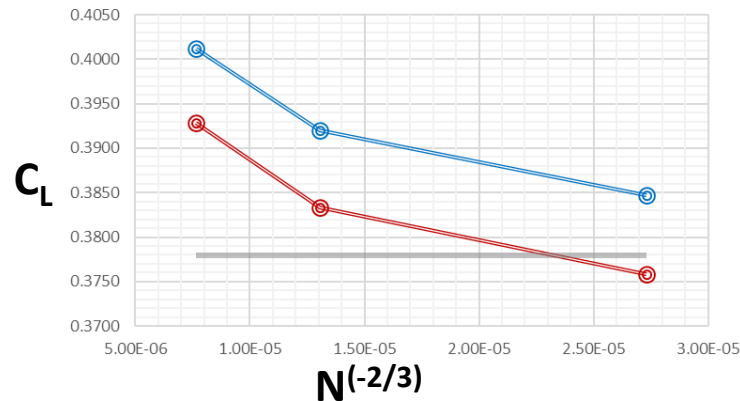
- Noticeable impact of corner flow and curvature corrections

- Curvature correction (CC) for SST based on Spalart-Shur Correction Term $f_{rotation} = (1+c_{r1})\frac{2r^*}{1+r^*}[1-c_{r3}\tan^{-1}(c_{r2}\tilde{r})]-c_{r1}$, $P_k \rightarrow P_k \cdot f_r$

- P. E. Smirnov and F. R. Menter. "Sensitization of the SST Turbulence Model to Rotation and Curvature by Applying the Spalart-Shur Correction Term". *ASME Paper GT 2008-50480*. Berlin, Germany. 2008

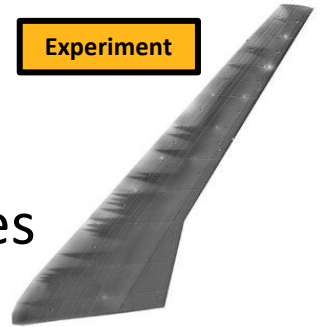
- Quadratic non-linear algebraic corner flow correction (CFC) to reduce corner separation $\overline{u_i u_j} = \frac{2}{3} k \delta_{ij} - 2\nu_t S_{ij} - C_{corner} \frac{1.2\nu_t}{\text{MAX}\left(0.3\omega, \sqrt{(S^2 + \Omega^2)/2}\right)} (S_{ik}\Omega_{kj} - \Omega_{ik}S_{kj})$

- Based on P. R. Spalart. "Strategies for Turbulence Modelling and Simulations". *International Journal of Heat and Fluid Flow*. 21. 3. 252–263. 2000

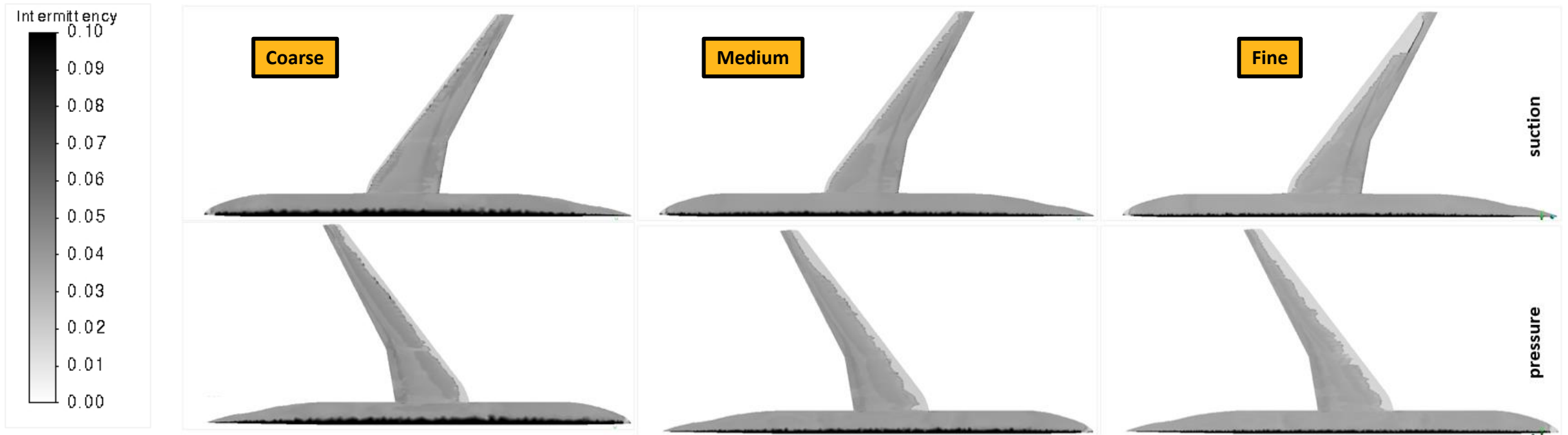


—○— TransitionSST
 —○— TransitionSST-cfc-cc
 — Exp.

Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$



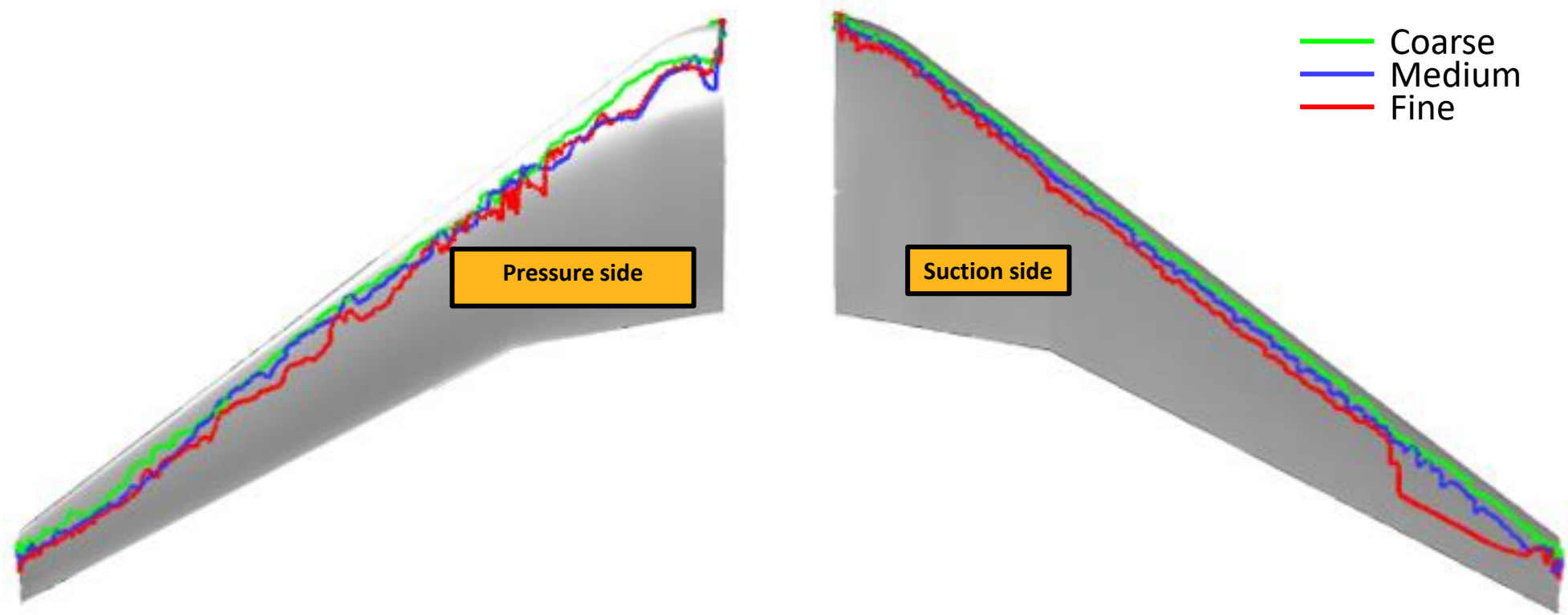
- Observation of surface intermittency on workshop-provided prism-tet meshes
 - Jaggedness of transition location along wingspan
 - Larger laminar region on fine mesh



Note: images shown are with corner-flow and curvature correction

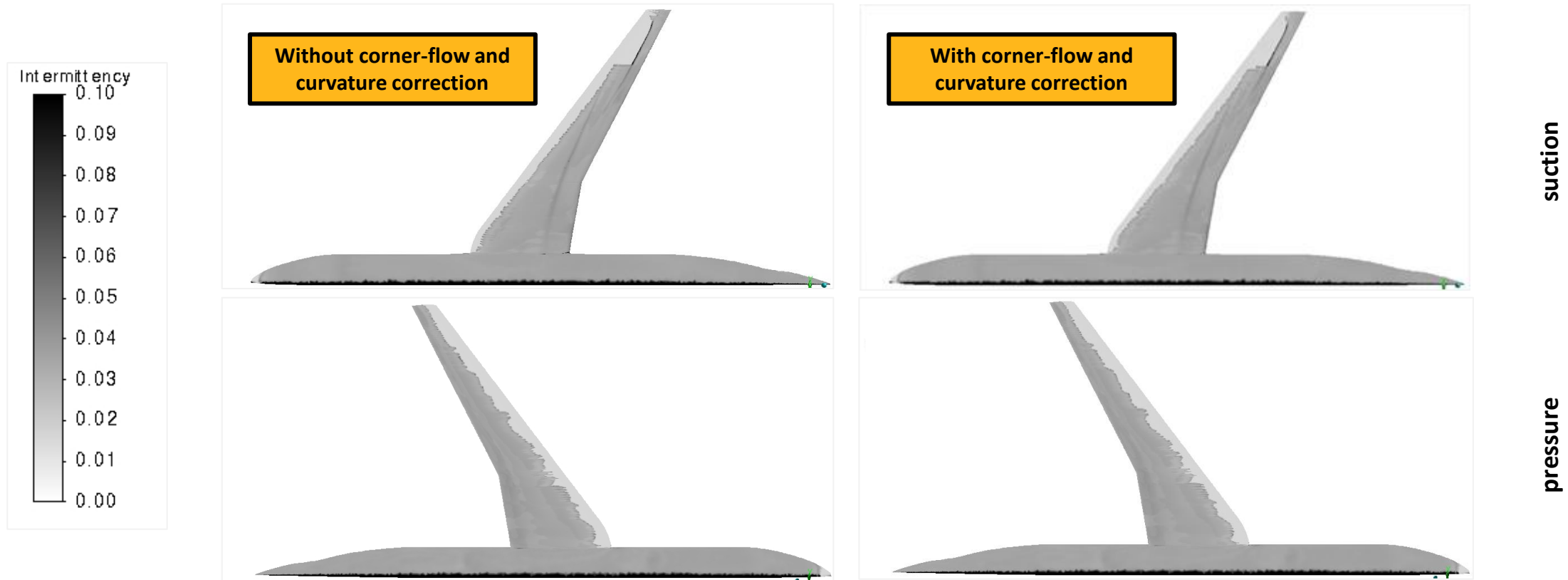
Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$

- Transition line estimation on workshop-provided prism-tet meshes



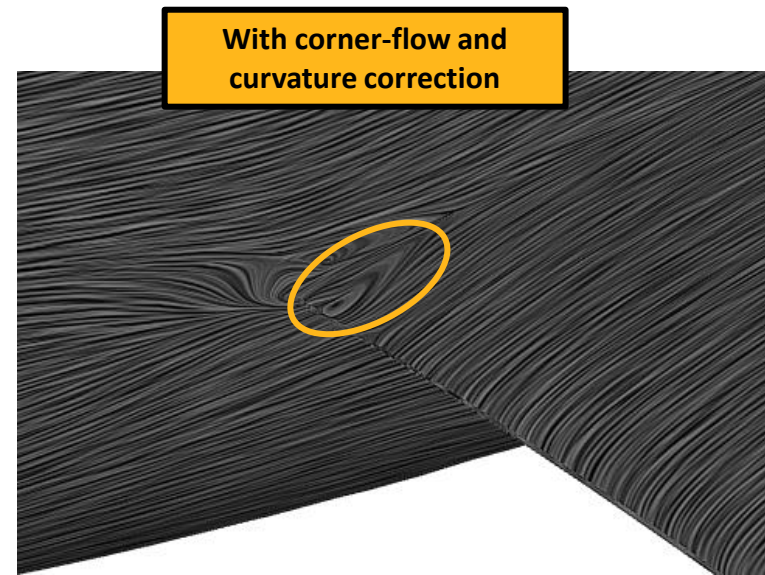
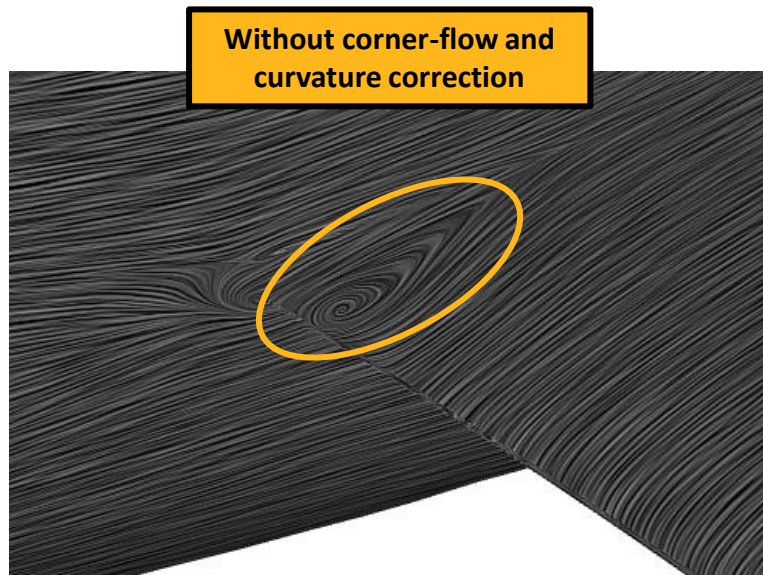
Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$

- No significant visible impact on transition location from correction terms

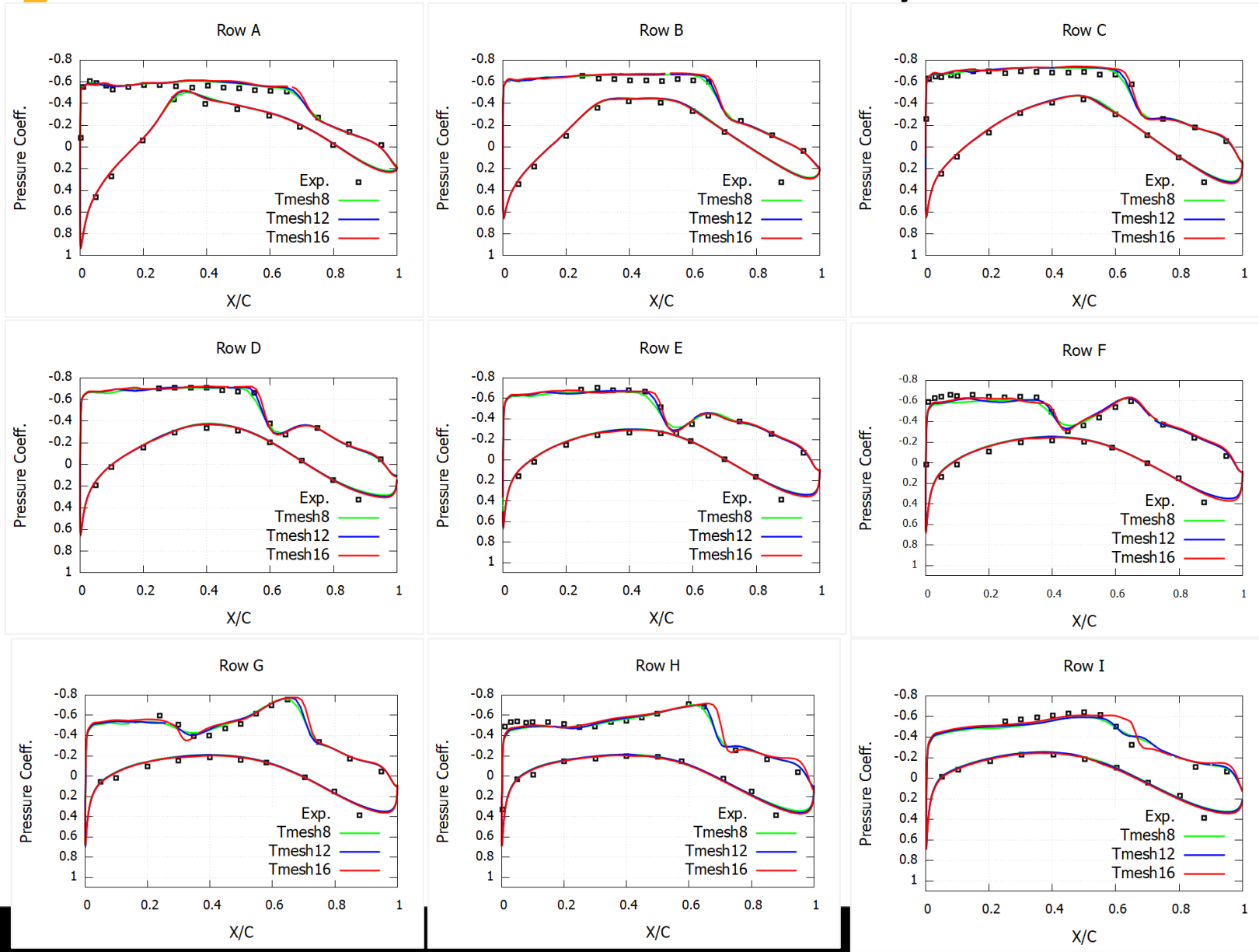


/ Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$

- Differences visible at trailing edge wing-body juncture
- As expected, and intended, reduced extent of separation region



Case 4A: Grid Resolution Study with Transition, $\alpha=1.98^\circ$



Pressure coefficient comparison with experimental data

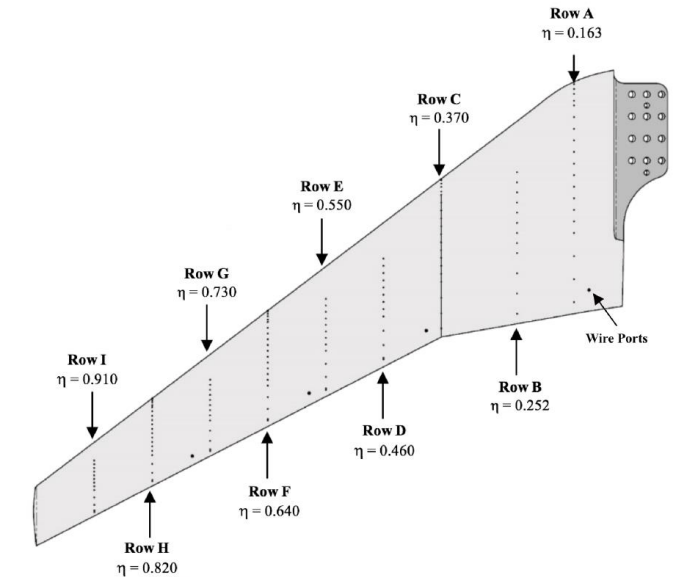
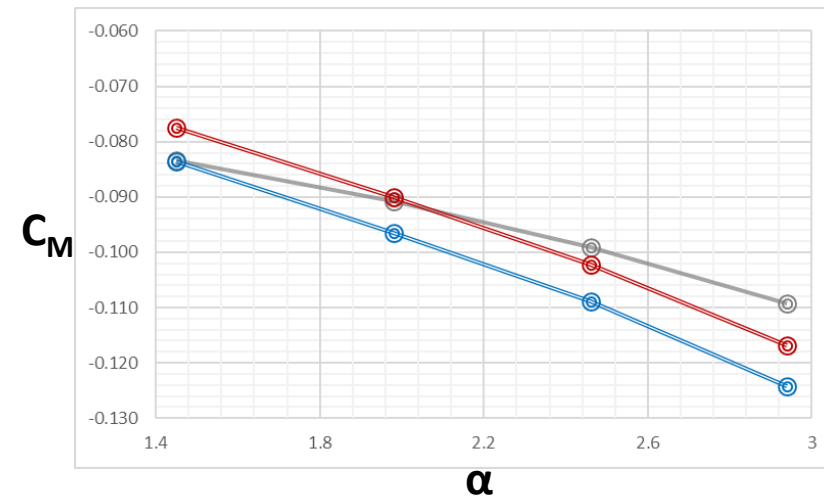
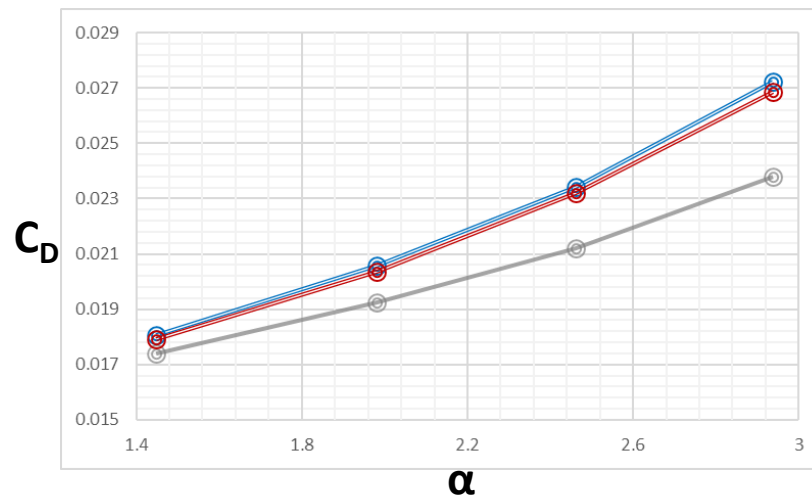
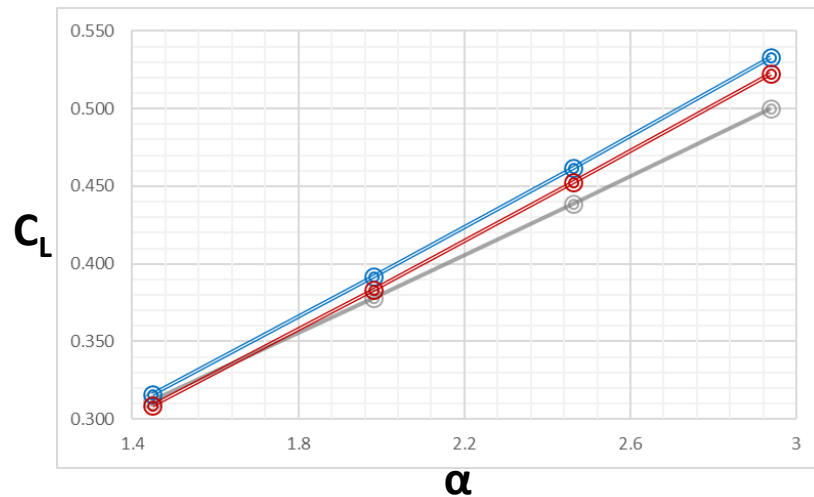


Figure 6.1 Planform View of Wing Upper Surface Showing Pressure Port Rows.

Case 4B: α -Sweep Study

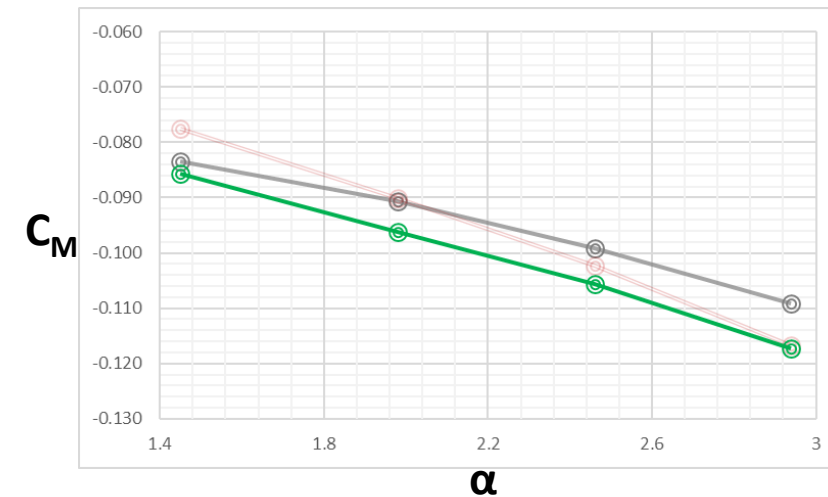
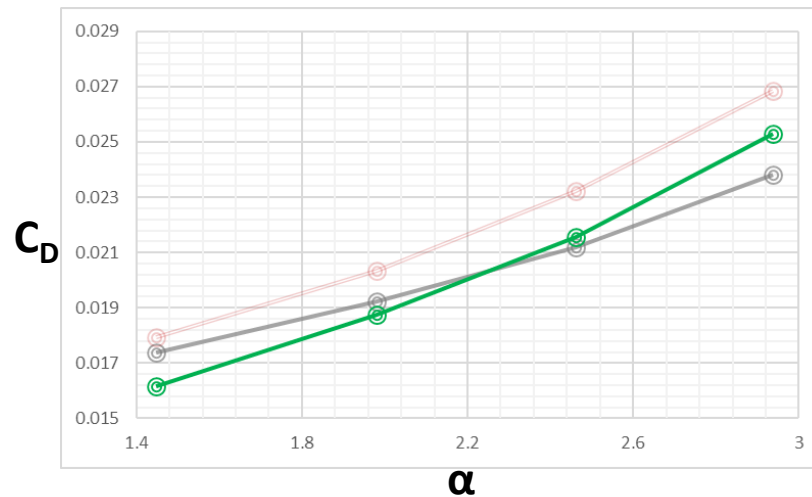
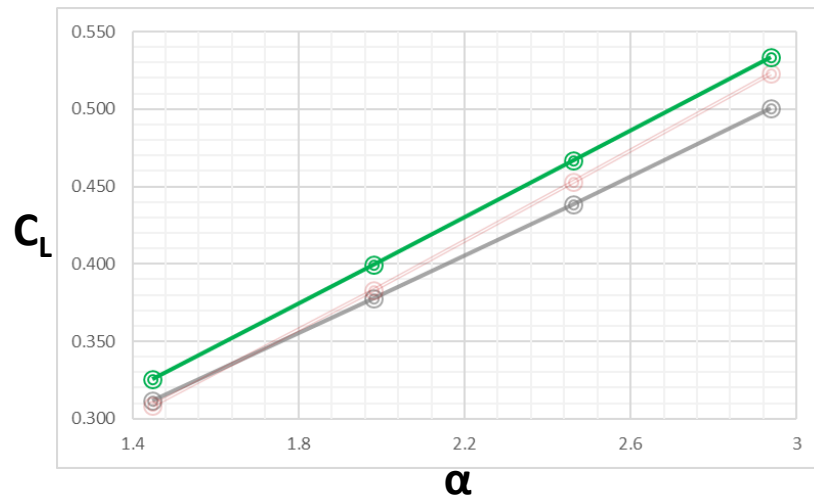
- Observation on integral quantities on workshop-provided medium mesh, with and without curvature and corner flow corrections
 - Correct trends
 - Slight difference in slopes for C_L and C_D , larger difference for C_M



TransitionSST TransitionSST-cfc-cc Exp.

Case 4B: α -Sweep Study

- Comparison between results on prism-tet (workshop-provided medium) mesh and structured hex (Ansys) mesh, both with curvature and corner flow corrections
 - Similar trends, some offset in all integral quantities
 - Lift slope closer to experiment with hex mesh

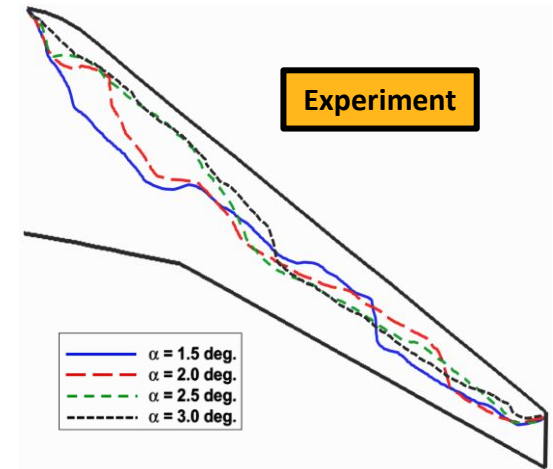
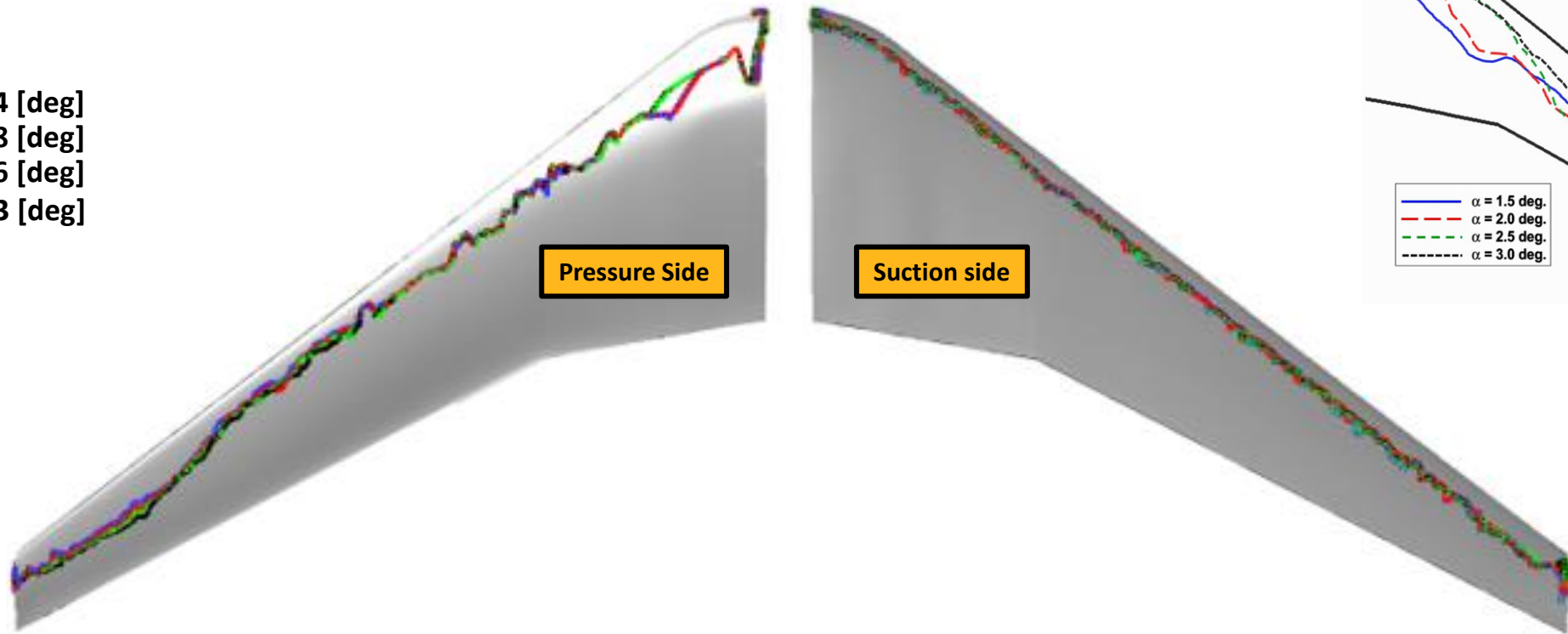


Hex Prism-Tet Exp.

Case 4B: α -Sweep Study

- Minimal shift in laminar region for α range medium prism-tet mesh

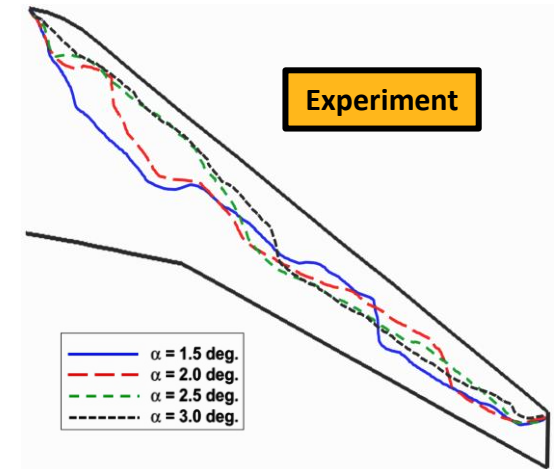
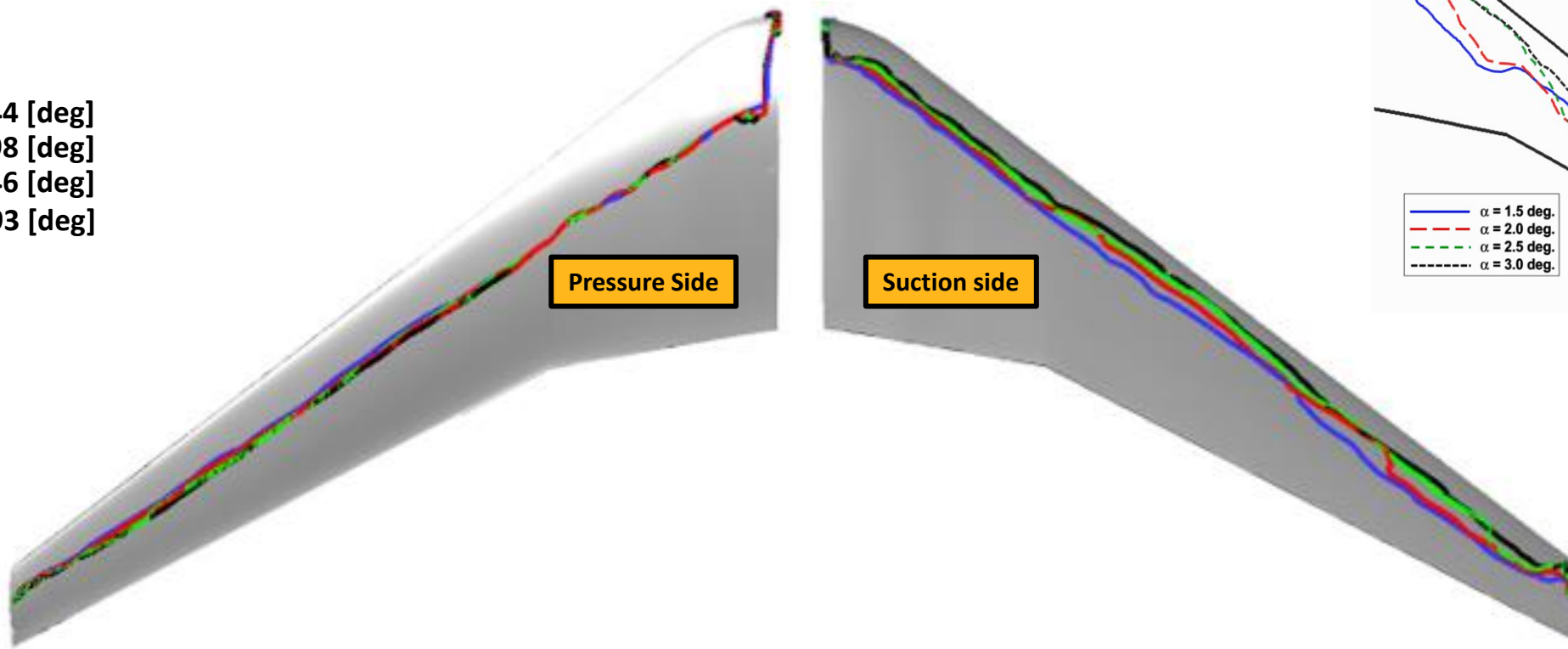
$\alpha = 1.44$ [deg]
 $\alpha = 1.98$ [deg]
 $\alpha = 2.46$ [deg]
 $\alpha = 2.93$ [deg]



Case 4B: α -Sweep Study

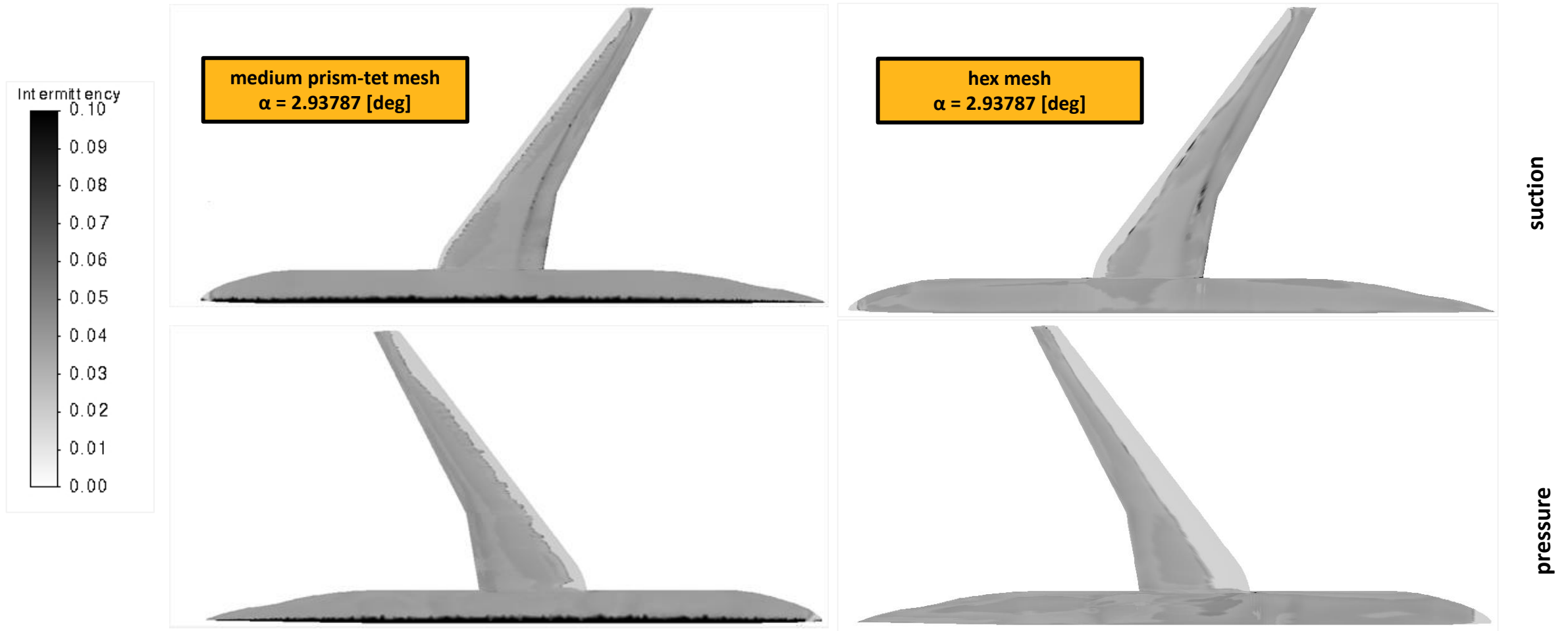
- Minimal shift in laminar region for α range on medium hex mesh

$\alpha = 1.44$ [deg]
 $\alpha = 1.98$ [deg]
 $\alpha = 2.46$ [deg]
 $\alpha = 2.93$ [deg]



Case 4B: α -Sweep Study

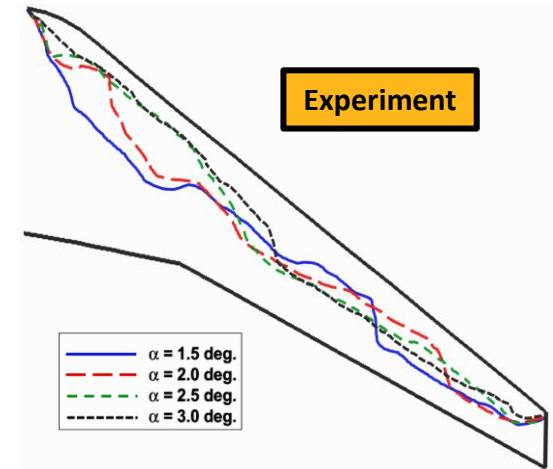
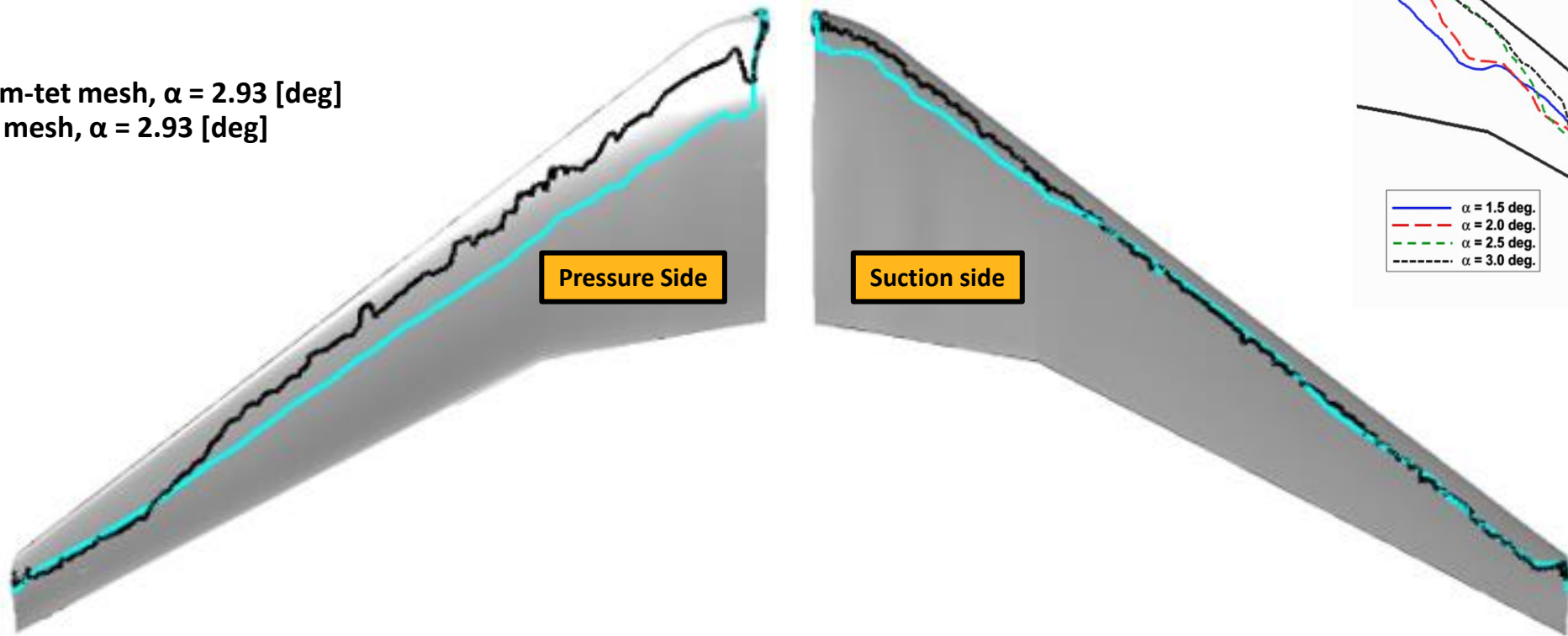
- Comparison: medium prism-tet mesh vs. hex mesh



Case 4B: α -Sweep Study

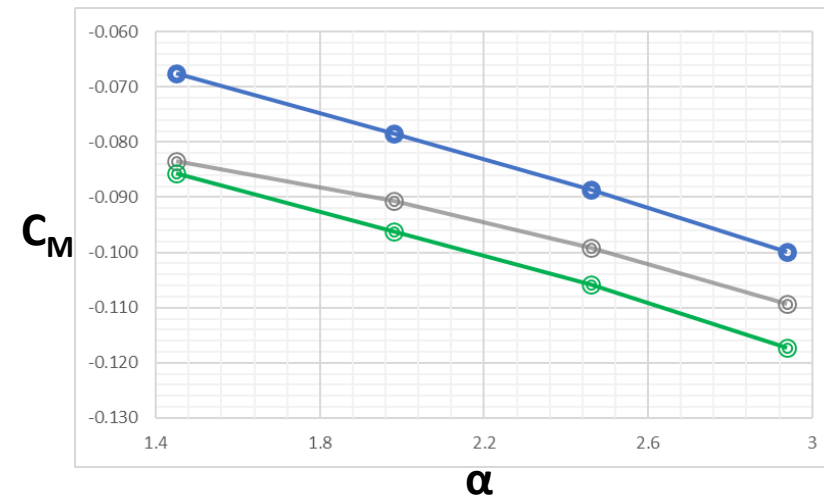
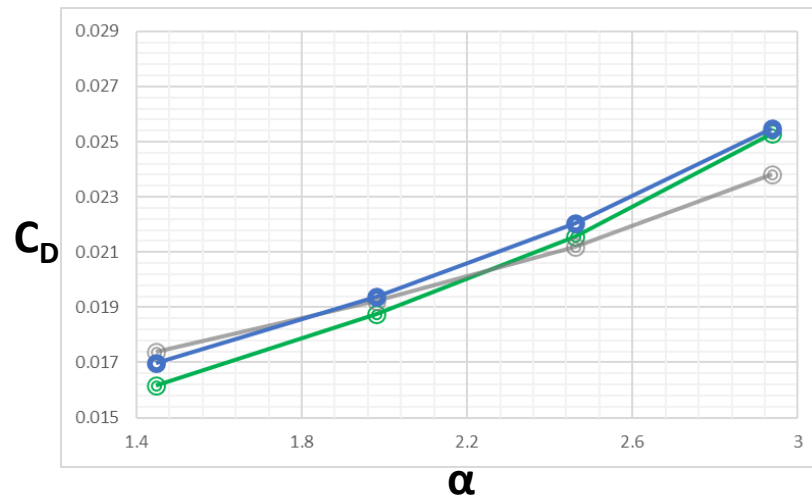
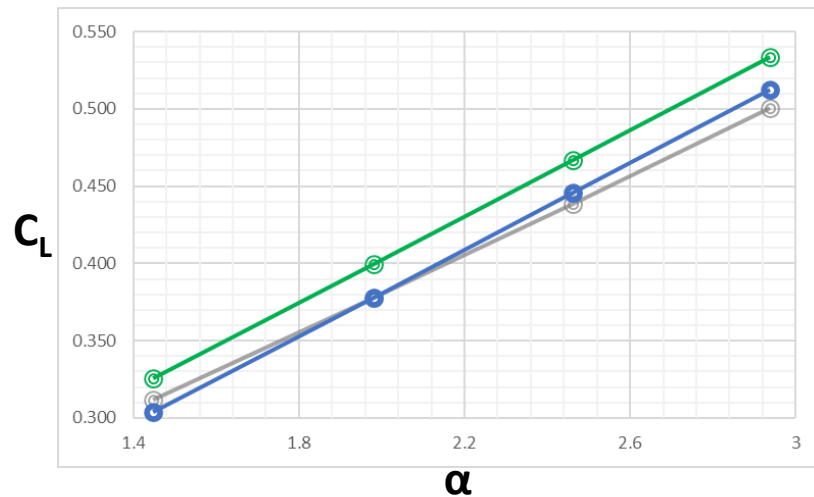
- Comparison: medium prism-tet mesh vs. hex mesh
 - Delayed and smoother transition line with structured hex mesh

— prism-tet mesh, $\alpha = 2.93$ [deg]
— hex mesh, $\alpha = 2.93$ [deg]



Case 4C: α -Sweep Study, Fully Turbulent

- Comparison transition and fully turbulent results on structured hex (Ansys) mesh, both with curvature and corner flow corrections
 - Shift of integral C_L and C_D closer to experiment
 - Further investigation needed



—○— With Transition —●— Fully Turbulent —○— Exp.

/ Summary and Outlook

- Verification Case submitted with Fluent SST model
- Test Cases 1, 2, and 4 submitted with Fluent SST- γ - Re_θ model
- Several overall conclusions and observations from NLF CRM test case
 - Results on NLF CRM model indicate grid convergence is not yet achieved with current meshes
 - Need to take care when looking at integral quantities alone
 - E.g. exclusion of transition gives 'better' results
 - Difficult to isolate effect of transition from other phenomena in NLF CRM flow
 - E.g. potential interaction between transition and corner separation at wing-body juncture
 - Large uncertainty in experimental results
- Outlook
 - Effect of free stream turbulence levels (intensity, viscosity ratio)
 - Comparison with other transition models (one equation γ -model, algebraic model)
 - Incorporation of correlation to account for transition due to crossflow
 - Further mesh refinement and/or mesh adaption

 **Ansys**



Additional Slides

Case 4B: α -Sweep Study, Pressure Coefficient Comparison, $\alpha=1.44^\circ$

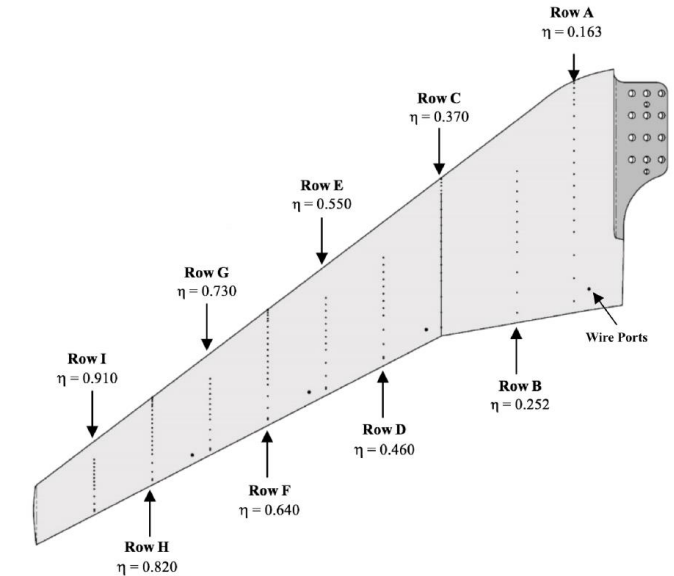
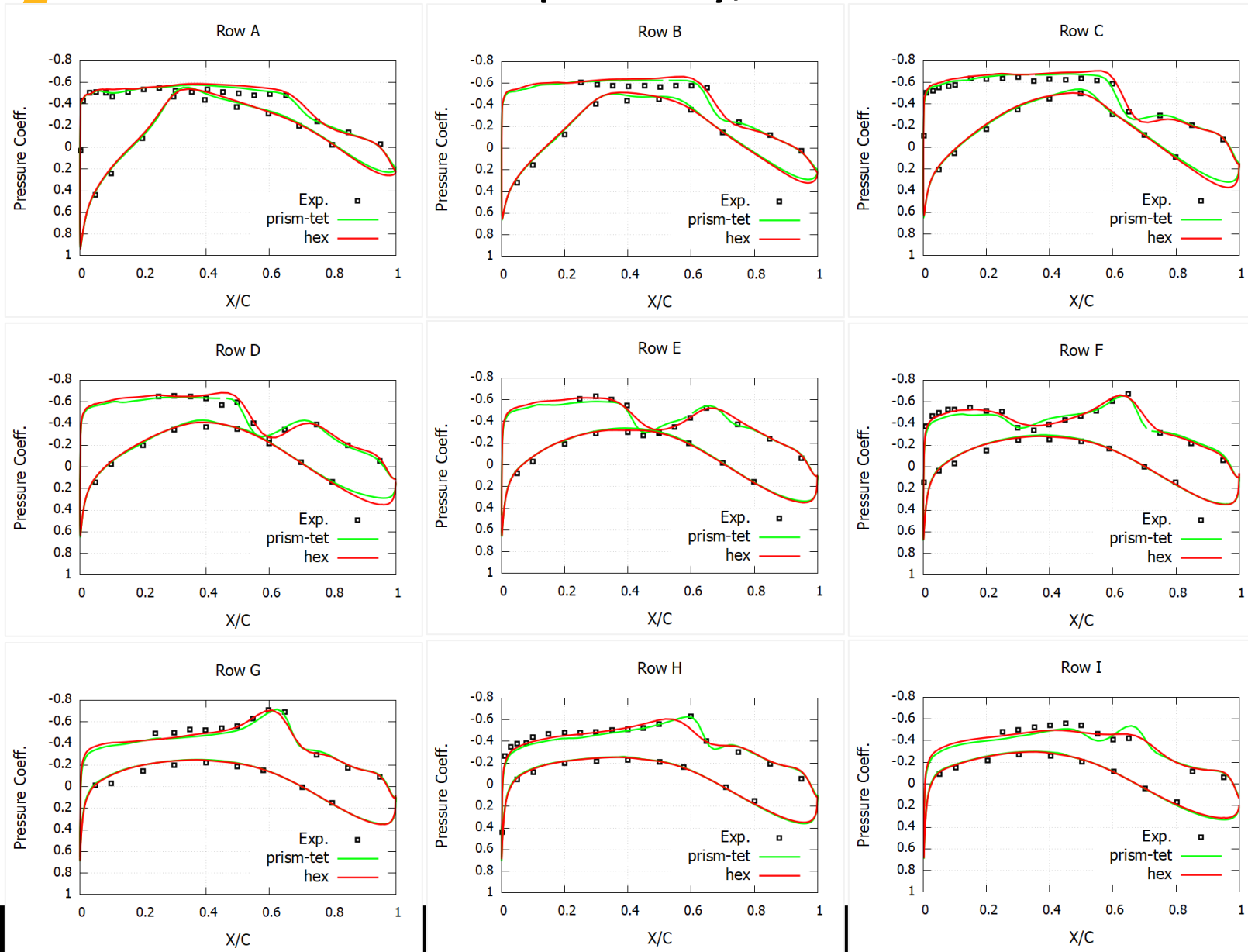


Figure 6.1 Planform View of Wing Upper Surface Showing Pressure Port Rows.

Case 4B: α -Sweep Study, Pressure Coefficient Comparison, $\alpha=1.93^\circ$

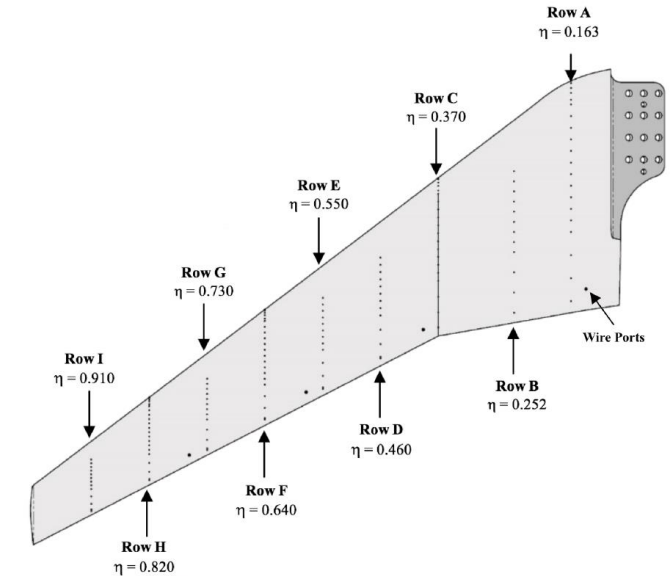
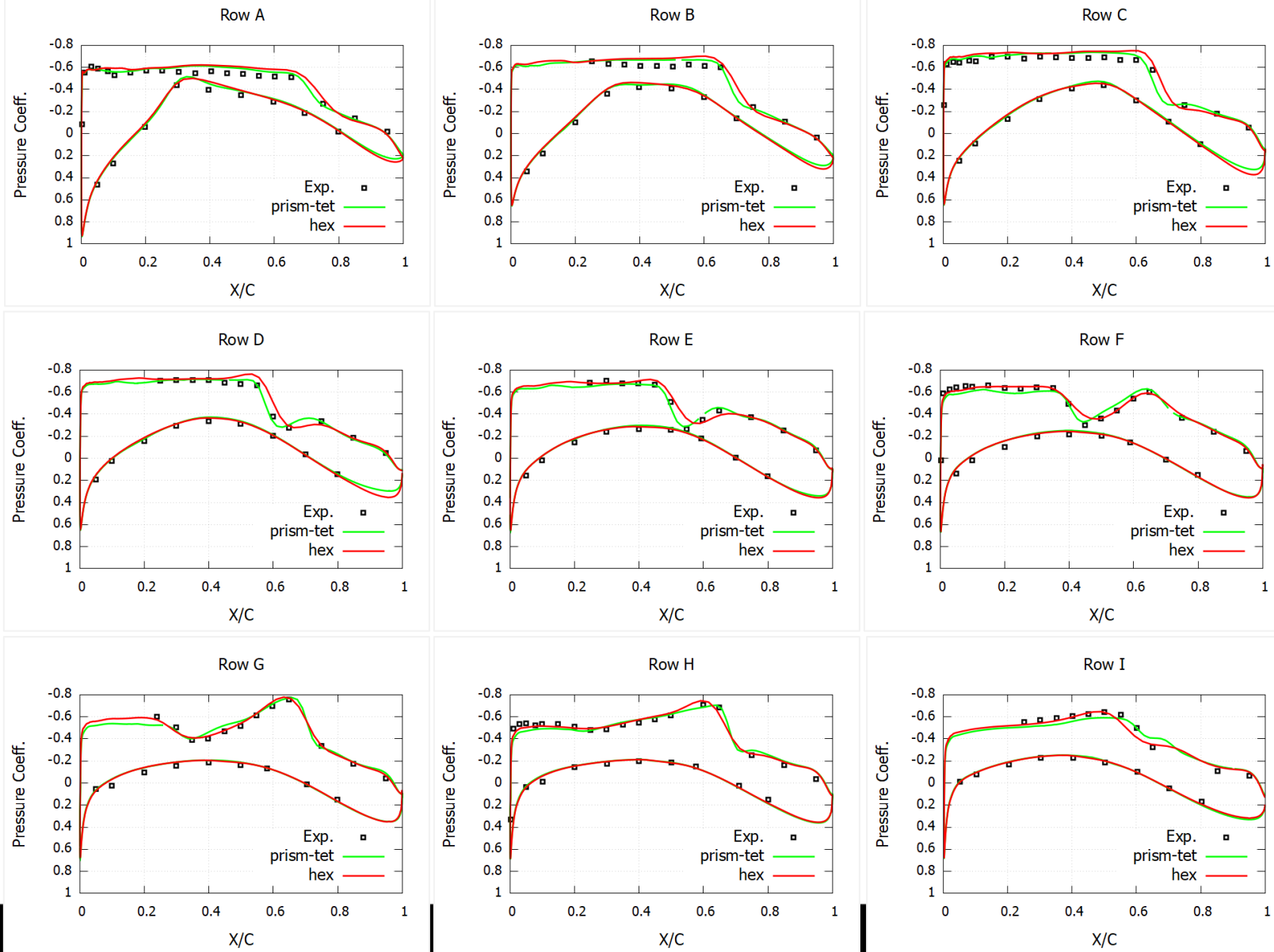


Figure 6.1 Planform View of Wing Upper Surface Showing Pressure Port Rows.

Case 4B: α -Sweep Study, Pressure Coefficient Comparison, $\alpha=2.46^\circ$

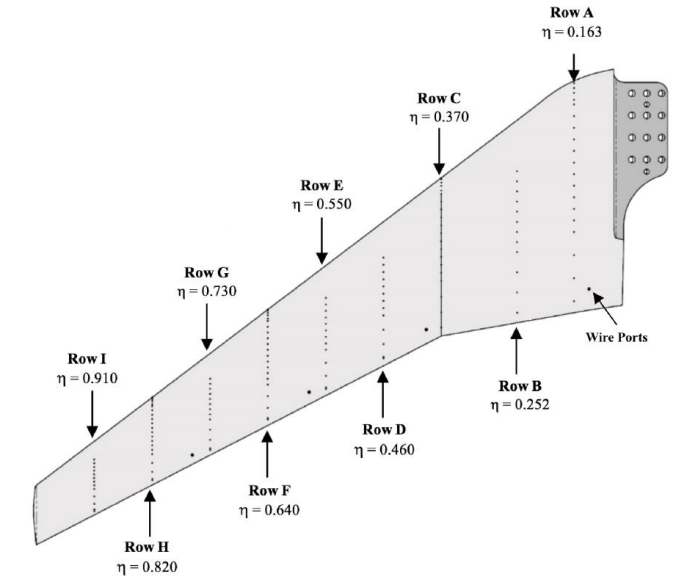
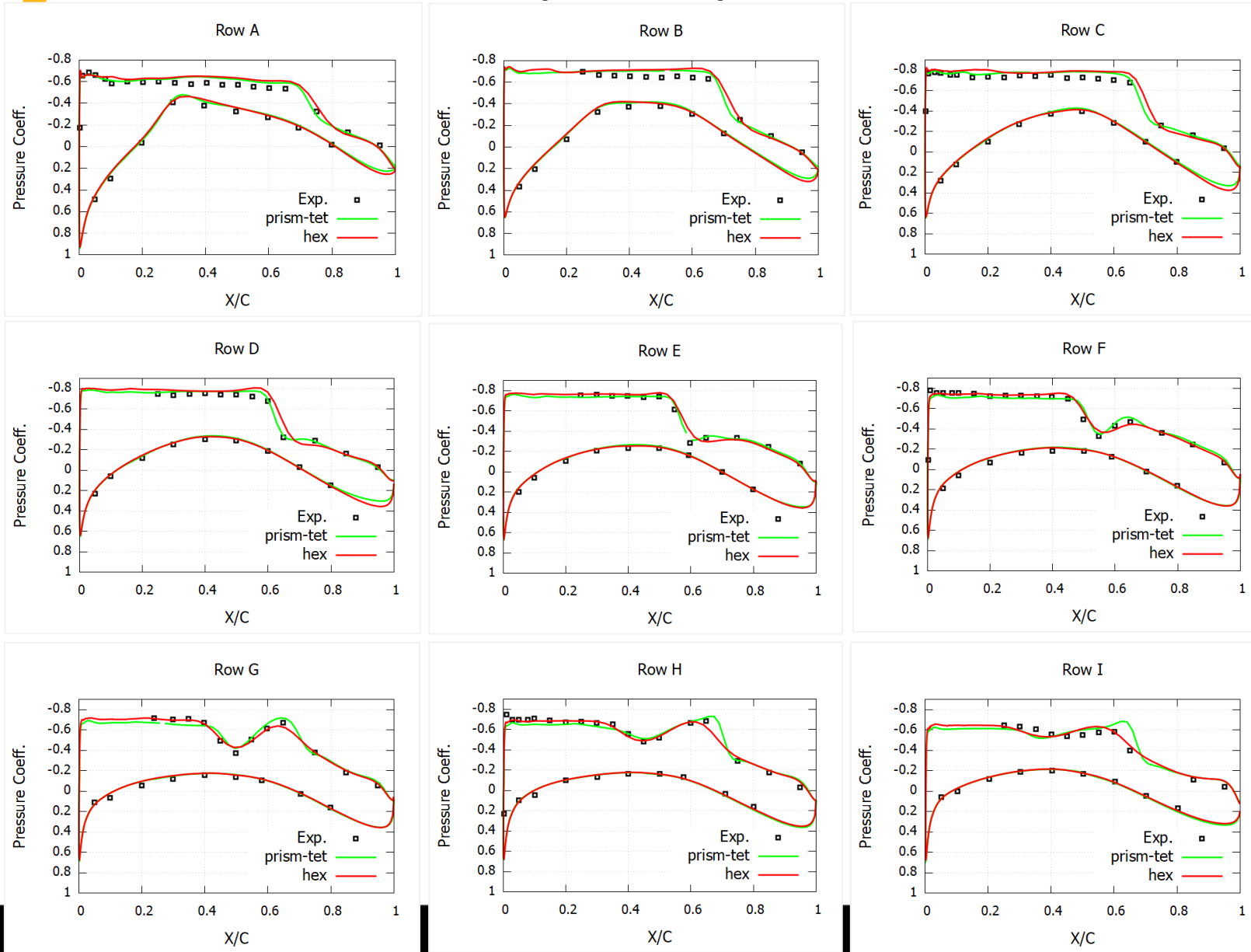


Figure 6.1 Planform View of Wing Upper Surface Showing Pressure Port Rows.

Case 4B: α -Sweep Study, Pressure Coefficient Comparison, $\alpha=2.93^\circ$

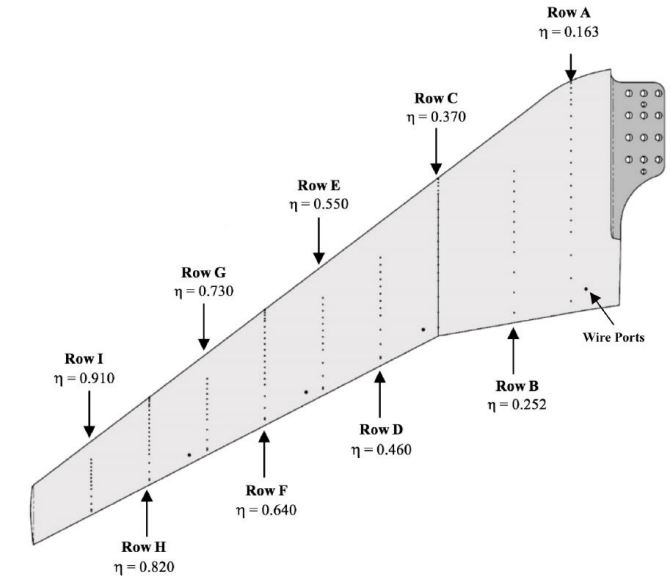
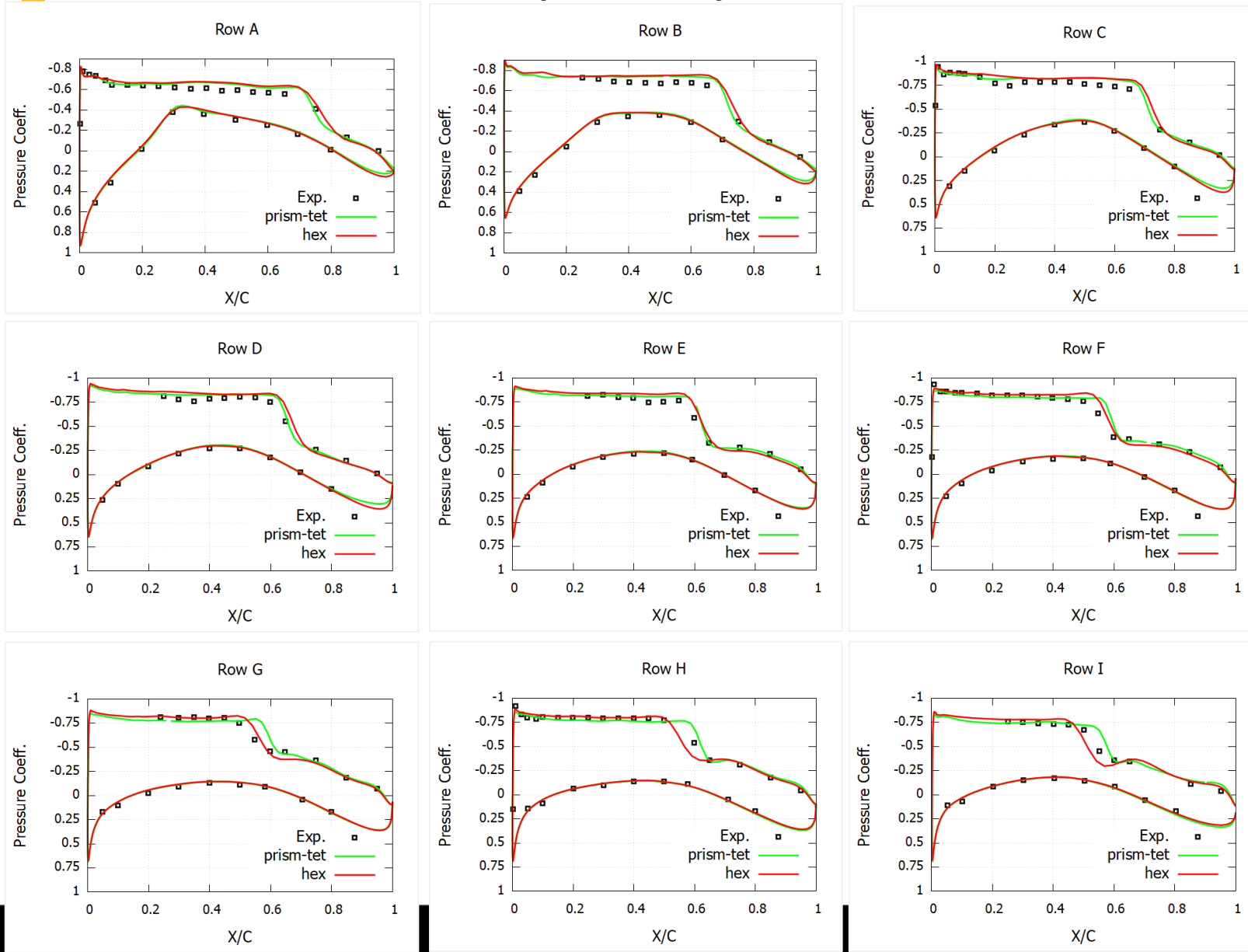


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